

Final Report

Temporomandibular Joint Disorder Diagnostics Device

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ABSTRACT

The purpose of this project is to develop a wearable device to record bruxism (tooth grinding and clenching) events and joint sounds during sleep. Diagnostic screening of bruxism is currently conducted in sleep labs through the use of electromyography (EMG). EMG requires patients to wear adhesive electrodes with wire attachments, limiting the patient's mobility and comfort during sleep. Studies utilizing these methods can produce inconsistent results due to the patient's discomfort in a different environment and the complexity of the equipment attached to their body.

This design project seeks to eliminate the necessity for sleep labs and allow patients to be screened comfortably in their homes while maintaining the accuracy and efficacy of standard sleep labs. Our design has unique features such as the hat-like data acquisition unit, that the patients will be able to wear comfortably in their home environment, and a laptop to acquire, store and display data to the user. As a result, the end product will be comfortable and user-friendly for both the patient and the clinician. The data acquisition in the patient's home will ensure that it is consistent with their natural sleeping habits. All in all, our design will greatly improve the screening and diagnosis of TMJD.

1. INTRODUCTION

1.1 Background

Temporomandibular Joint Disorder (TMJD) affects approximately 35 million people in the United States. It can cause problems with eating, drinking, swallowing, talking, making facial expressions, and even breathing in people who suffer from it. Bruxism can wear down the fibrocartilage discs in the jaw, which makes it difficult to open and close the mouth. Bruxism, the act of grinding or clenching of the teeth, is a common symptom of TMJD that clinicians use to diagnose it.

Currently patients who are suspected to have TMJD or exhibit signs of bruxism through wear on the teeth are subject to spend a night in a sleep lab, in which they are connected to electrodes while sleeping. Those electrodes are connected to machines through wires that record and analyze the activity of the masseter and temporalis. A trip to the sleep lab is inconvenient for many patients, many of whom also have sleep apnea and typically use a breathing machine.

1.2 Purpose of the Project

The TMJD Diagnostics Device aims to make sleep labs for TMJD diagnosis superfluous. It will make it possible for the muscular activity associated with

bruxing to be recorded in the patient's home. This would take the necessity of transporting a breathing machine out of the diagnosis of TMJD for patients with sleep apnea, and be more cost effective for patients as well as their insurance companies.

1.3 Previous Work Done by Others

1.3.1 Products

A current low-cost bruxism diagnostic device is in the market. The BiteStrip is a single-use disposable device used by the patients at home. It is a miniature electronic system consisting of: two pre-gelled skin EMG electrodes and an EMG amplifier, for acquiring nocturnal EMG signals from the mastication muscles; a CPU for running real-time software that analyzes EMG strength patterns and for detecting and counting each bruxing episode; a permanent chemical display for presenting the study outcome in the morning and a lithium battery. All the elements are integrated onto a small lightweight plastic film that is attached to the patient's cheek. The BiteStrip device is shown in Fig. 1.

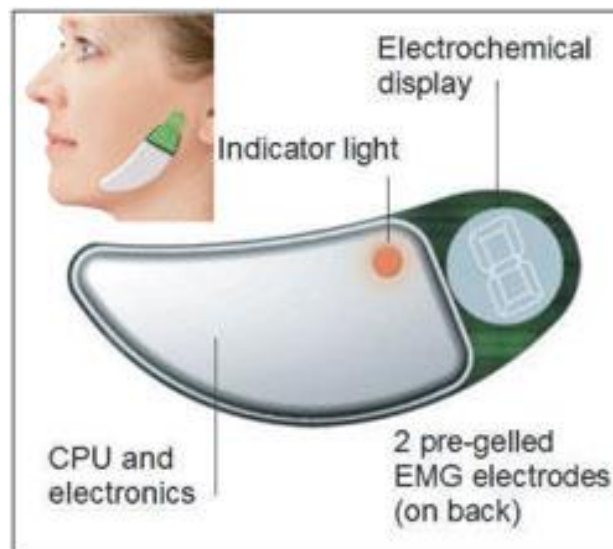


Figure 1. Components of the BiteStrip

Its indications correlate well with comparable indications from formal sleep lab studies. It is available through health providers worldwide at a very low price to the public as a self-administered or prescription test. Relevant patents were applied for, and clinical studies are in process in well-known sleep labs to prove its accuracy.

In using Bitestrip, the patient is required to perform at least two maximal voluntary clenches during the first 30 minutes by biting on a wooden spatula provided in order to establish the threshold which is set at 30% of the average EMG amplitude. The BiteStrip counts each EMG peak stronger than the threshold for a

period of up to six hours. The patient then returns the Bitestrip to the clinician for interpretation of the results.

Despite the advantages offered by Bitestrip, the device presents some limitations. In the first place, the study requires a minimum of 5 hours. If the Bitestrip is removed earlier than this minimum period, an error will occur. Moreover, this device does not save the EMG signals, which may be useful for the clinician in order to assess an accurate diagnosis. Bitestrip only provides the number of bruxing events. This information will not allow the clinician to distinguish between teeth grinding and clenching, nor record the intensity of the clenching or grinding or the time when these events occur.

Sakagami, Horii, Ino, Matoba, Kato and Kawanami developed a portable nocturnal bruxism monitoring and analysis device in 2002 and verified its accuracy and easiness of use. Their bruxism diagnostic system consisted of two parts: the portable bruxism monitoring and analysis device, and the software that was installed to a computer.

The monitoring and analysis device (Morita MFG) was equipped with a microcomputer to auto-analyze the data. Due to the small size of this device and its light weight, it could be either placed on the forehead, or inserted in a pocket of a jacket. The device had two sets of data import connectors for pick-up cables, which were hooked to the disposable electrodes (Duotrode®, Myotronics Inc., USA) attached either to both sides of the cheek over the masseter muscles, or to both sides of the temple over the temporalis muscles. In order to launch the device, the user would push the start button on the side of the device. After amplification and processing of the EMG signals, these were compared to a manually set threshold level. The device provided the total number of bruxing events as well as the lasting time of each bruxing event. Finally, the recorded data was transmitted into the computer via serial port. The device was equipped with EEPROM and the data is recorded on the memory to the maximum of 676 data sets in one night.

Although the authors who carried out the study verified the accuracy of the device, and the subjects of the study declared that it was easy to use, this device does not provide comfort and mobility to the patients due to the presence of wires. Moreover, serial communication limits the speed of data acquisition.

The components of the bruxism monitoring device is shown in Fig. 2. The test setup for data acquisition is shown in Fig. 3.

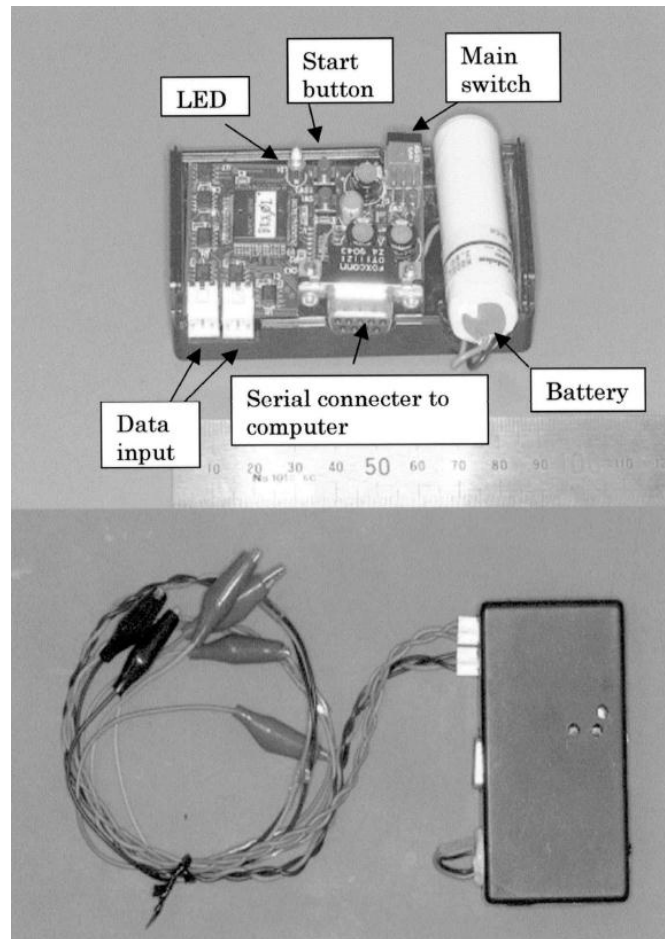


Figure 2. Components of the bruxism monitoring and analysis device developed by Sakagami, Horii, Ino, Matoba, Kato and Kawanami.

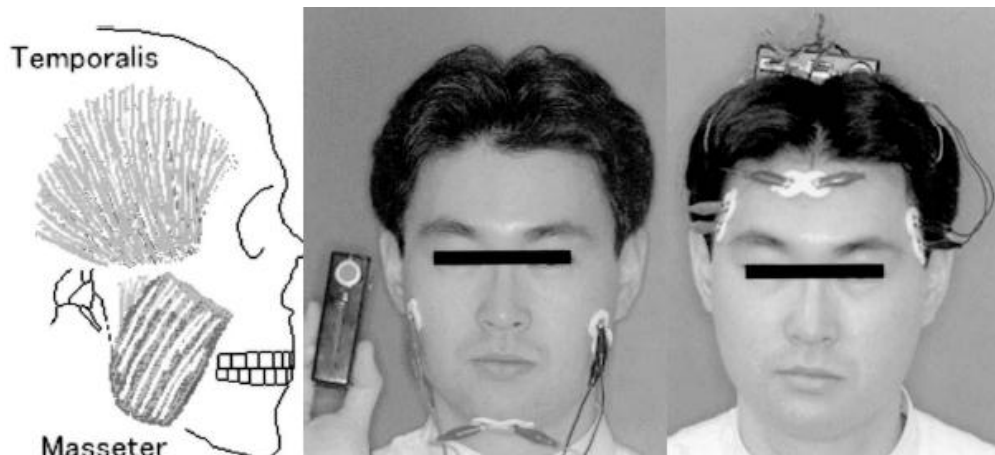


Figure 3. Left: The temporalis and masseter muscles. Center: Electrodes attached to the cheek for the data acquisition from the masseter muscles, and to the chin for earthing. Right: Electrodes attached to the temple for the data acquisition from the temporalis muscles, and to the forehead for grounding.

1.3.2 Patent Search Results

The Bitestrip described above has applied for relevant patents and clinical studies are in process in well-known sleep labs to prove the accuracy of this device.

In addition, after patent search, only one more device was vaguely related to the purpose of our project. It is a “Measuring device for quantifying the severity of bruxism”, US patent #5,911,576, comprising of a thin shell formed to the shape and elastically retained to one or more teeth. The shell consists of many layers of different colors. The outer layer of the shell, when worn out by clenching and grinding, reveals an inner layer. This way, the regions of wear may be analyzed to determine the extent of the bruxing activity. However, this device does not provide the EMG signals for accurate diagnosis and may not be comfortable to use since it may interfere with normal breathing.

1.4 Map for the Rest of the Report

The remaining portion of this report will consist of the design, constraints, safety issues, impact of engineering solutions, life-long learning, budget, timeline, individual team member contributions, and additional data to support our final proposal.

2. PROJECT DESIGN

Originally we had proposed three alternative designs for the realization of the project. Alternative Design I had been chosen as the optimal since it is more economic and would require less setup than Alternative Design II, which incorporates four BiteStrip-like adhesives with Bluetooth wired into each one. Alternative Design III would be significantly less costly by incorporating memory into the unique hat design proposed. This design would make the computer unnecessary, but available memory space for a long test like the one described will be difficult to find. The memory would need to be wiped in-between tests, which may require the patient to do that him or herself if the test is to be repeated for several nights. Then, Alternative Design I was determined to be optimal for the convenience of the clinician and the patient. The final product is a slight variation from Alternative Design 1, but does not vary much from its scope. A brief overview of the three alternative designs is presented below, followed by a detailed description of the subunits that comprise the optimal design.

ALTERNATIVE DESIGN I

The optimal proposed TMJD device will consist of two major parts: a hat-like data acquisition unit and a miniature laptop to acquire and display the data to the user.

The hat device will house nine electrodes, a battery pack, a Bluetooth device, and a series of filters and amplifiers in an integrated circuit. The nine electrodes will be used to acquire signals from the left and right masseter and temporalis of the patient, the four muscles associated with bruxing and clenching. Two electrodes are needed for each muscle, and an extra electrode will be used as a baseline set on the forehead of the patient. The electrodes will be reusable to minimize the amount of setup done by the patient in-home. The electrodes, RC filtering, diode protection, and amplification circuitry is shown in Figure 2. The 1N4001 diodes will be replaced by FDH333 low-leakage diodes in the physical to ensure that no current is transferred to the patient (Multisim does not have a library consisting of FDH333 diodes). Additionally, a 1N4001 diode will be added to each diode at the positive terminal of each op amp to ensure maximal protection of the power supply circuit. This limits the damages that may be caused if the user inserts the batteries backwards.

Two nine-volt batteries will power the electrical devices. The power supply circuit is shown in Figure 1a, and its simulation is shown in Figure 1b. It is evident that the dual power supply can provide +9 V and -9V for a total of 18 V. A dual power supply is necessary to power the AD620 instrumentation amplifier. The two 22 pF tantalum capacitors stabilize the current. The filters and amplifiers will receive signals sent by the electrodes. They will filter out ambient and artifact noise and amplify the signal so that it can be transmitted via Bluetooth to the laptop. First-order RC filters will be coupled directly to the electrodes, and active filters will follow each instrumentation amplifier. The lowpass active filter circuitry is shown in Figure 3a, along with its AC analysis in Figure 3b. The passband drops sharply at 500 Hz, indicating that the filter has been designed properly. The phase shift shown in Figure 3b will have a slight effect on signal, but will not distort the amplitude. The highpass active filter circuitry is shown in Figure 4a, along with its AC analysis in Figure 4b. Once again, the passband to stopband transition is steep, indicating that the filter will perform sufficiently. The phase shift shown in Figure 4b will likewise slightly effect the signal, but will have no effect on the amplitude. The 60 Hz notch filter is shown in Figure 5a, along with its AC simulation in Figure 5b. This filter is based on the Twin-T design, which provides a high Q and deep notch, suppressing only frequencies in the 60 Hz range. The lowpass and highpass active filters were designed with FilterLab software to quickly design fourth-order Butterworth filters, whereas the 60 Hz notch filter was designed from previous knowledge of the Twin-T notch filter.

The miniature laptop will be Bluetooth-enabled and will be equipped with an executable file designed in LabVIEW. This executable file will acquire data and save important events, as well as convert the hertz units to Newtons, to make the data something tangible for the clinician. The program will be setup so that the patient simply has to turn on the laptop and press start on the program for it to start recording. The program will automatically save the necessary data and process it, so that it will be usable for the clinician once the laptop is brought back to them. The steps to activate the device are displayed in Figure 6.

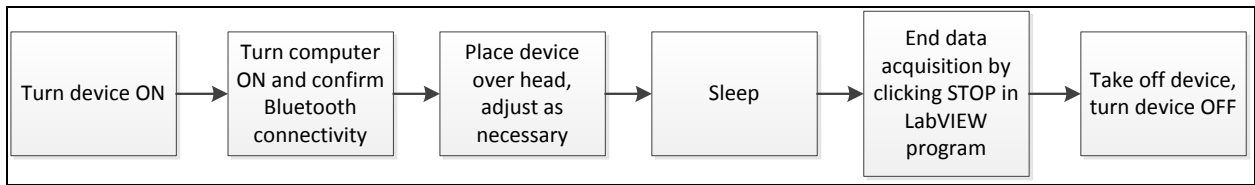


Figure 4. *Process to activate the device*

Figure 4 displays the device's user-friendly minimal interface; the patient does not have to do much to acquire data.

The reader should note that Alternative Design 1 is a viable option for future applications. Alterations to this design concept were implemented to account for time and other constraints.

ALTERNATIVE DESIGN II

An alternative design to the one described previously introduces a change to the mechanical design of the device while maintaining the same modality of signal acquisition and data collection, analysis and display. The proposed mechanical design resembles that of the existing diagnostic device BiteStrip.

As in Alternative Design 1, two reusable skin electrodes will be used to collect the electromyography data from one muscle. The corresponding circuitry will perform corresponding amplification and filtering to the signals. The data will then be sent via Bluetooth to a computer provided to the patient. This time, however, Instead of enclosing the circuitry in the hat worn by the patient, it will be integrated into a miniature lightweight film similar to the one of BiteStrip. The device will be self-adhesive to be placed by the patient over the Masseter and Temporalis muscles before going to sleep. As in the previous design, a program contained in a LabVIEW executable file will be used for collecting data and performing corresponding analysis and display of relevant information to the clinician.

The integration of the elements into a miniature film would avoid exposure of wires and circuit components to the user. The small size and the light weight of the device would also provide major comfort to the patient during sleep. However, since ideally the clinician would require collection of electromyography signals from the four muscles, the cost of the device would increase significantly since four Bluetooth modules would be needed for this design.

This design maintains the advantage of wireless data transfer to the computer presented in Alternative Design 1 while introducing an alternative to the mechanical design of the device that seems to provide comfort to the patient. However, four identical devices would be required for a more accurate and complete diagnosis. This translates into a significant increase in the cost for this

design. On the other hand, the Alternative Design 1 uses the same modality of data acquisition, transfer and analysis but at lower cost. Moreover, it introduces a unique hat design. Due to this, the Alternative Design 2 is not considered the optimum for now.

ALTERNATIVE DESIGN III

An electromyography circuit will be secured into the hat design and positioned superior to the patient's head, similar to Alternative Design 1. Positioning the circuit on top of the patients head eliminates the possibility that the patient will damage the circuit during sleep. This placement also improves the comfort of the device, as the patient will never lean on the circuit. The circuit will acquire signals from nine electrodes placed over the muscles of mastication, provide protection to the patient and the components, filter data outside of the EMG bandwidth, and amplify the signals to a desired level. The circuit is similar to alternative design 1; however the communication protocol and memory storage is altered to reduce the final product cost.

Once the data is processed and amplified by the AD620 instrumentation amplifier, it will be sent to a memory storage component in the circuit. When the user has finished recording, the data will be loaded onto a computer equipped with LabVIEW via serial RS-232 communication protocol. To avoid the necessity of the computer having a license for LabVIEW software, an executable file of the program will be stored on an accompanying CD-ROM. The user will simply connect a serial cable to the device and to the computer, and the data will be automatically transferred to a LabVIEW measurement file.

The LabVIEW program will be simple and easy to use. The clinician will load the executable file onto a computer of their choice and run the program. A serial port will then connect the device to the computer and data transfer will commence. Once the data has been loaded onto the clinician's computer, additional processing will be implemented to present useful diagnostic information. This may include the total time spent bruxing, the total number of bruxing events, the time at which bruxism occurred, and the maximum force and pressure during bruxism.

This alternative design eliminates the necessity for a notebook computer, which reduces the cost by nearly 70%. This cost reduction is incredibly desirable, but memory availability becomes an issue. Since data will be sent to a memory chip overnight, eight or more hours of data could be stored. It may not be possible to store this amount of information onto one memory chip. Additional memory chips may need to be implemented, and entire memory wipes may need to be used each time the device is powered on. The transfer of data may also become an issue, as there would be no way to check if the data displayed in the LabVIEW program is valid or if it were corrupted or overwritten in the storage or transfer process. A direct link to the LabVIEW program as described in the first alternative design is the most desirable method, per request of the client. The exact time at which bruxing

events occur must also be recorded during the session, which poses an additional challenge.

This design is certainly worth considering because of the drastic reduction in cost. However, the memory availability of integrated circuits needs to be researched more in order to determine if this design is feasible. Due to the client's request that a notebook computer accompany the device, this design is not considered optimal at this time.

2.1 Optimal Design

2.1.1 Objective

The TMD Diagnostics Device utilizes electromyography (EMG) to obtain biosignals from the muscles involved in mastication, including the left and right temporalis muscles, and the left and right masseter muscles. These EMG signals will be used to determine if the patient is bruxing or clenching during sleep, two major contributing factors to temporomandibular joint disorder (TMD). EMG is currently utilized in TMD sleep studies with significant efficacy in determining bruxing events. However, sleep studies are expensive and uncomfortable for the patient, resulting in data that is inconsistent with their sleep habits. This device allows the patient to perform a comfortable EMG study in their home environment and acquire accurate data.

The signals are obtained from disposable electrodes without the use of adhesive gel, providing a superior level of comfort for the patient.

The device is comprised of a modified Neuroband, a wearable device traditionally used for electroencephalographs (EEG). The disposable electrodes are secured in the Neuroband using snap electrode leads placed inside the device over the muscles of mastication. The snap electrode leads are removable so that the device can be washed between uses. The electrode leads are connected to a DIN connector cable which is attached using a D-sub connector to the circuitry. The circuit is enclosed and is connected via USB to the laptop computer. Velcro® is utilized to allow for minor adjustments and achieve an optimal fit.

The EMG signals are sent serially to a laptop computer. An executable LabVIEW program automatically loads each time the computer is powered on. The interface is easy to use and provides sufficient help information in addition to a detailed user manual. The user will simply run the program and initiate the data acquisition process. The program will have the capability to analyze, send, store and display data. The raw data will be processed into useful diagnostic information that may be presented to the clinician.

In order to test the device, subjects with TMD and control subjects will be employed in clinical trials. Therefore, an institutional review board (IRB) must be

applied for in consideration of clinical trials. This will be possible with the help of the UConn Health Center and School of Dentistry.

2.1.2 Subunits

2.1.2.1 EMG Circuit

Analog circuitry must be utilized in order to amplify and filter the electrical signals obtained from the facial muscles. The electromyography (EMG) circuit can be visualized by means of a flowchart created using Microsoft Visio 2010, as shown in Fig. 5.

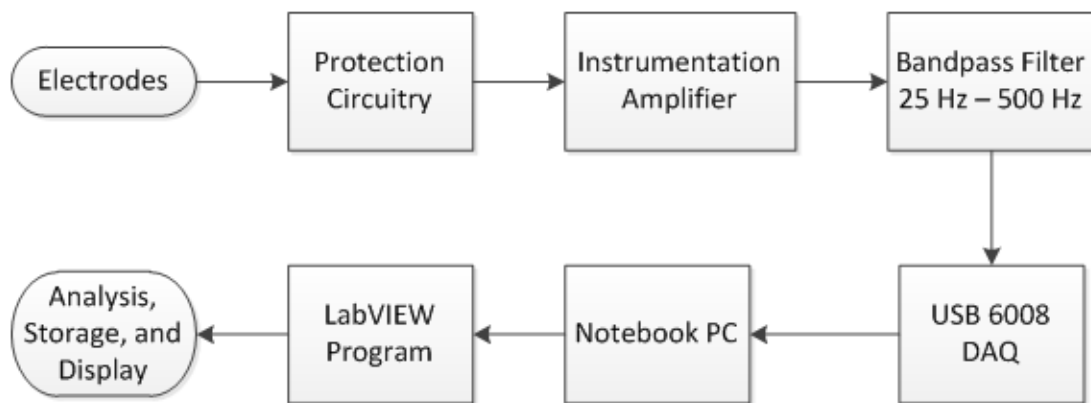


Figure 5. Electromyography circuit flowchart

The components of Fig. 5 will be discussed herein.

2.1.2.2 Power Supply

The circuit operates from a +12 V, -12 V, +5 V AC-DC wall transformer. -12 V was necessary to provide sufficient voltage to the operational amplifiers (op amps). Future applications should employ a DC-DC converter with a switching, inverting regulator with buck-boost capabilities to convert the positive voltage supply to that of opposite polarity. This was not included in the final product due to a relatively late change in design that did not allow for additional circuit design. The power supply circuitry is shown in Fig. 6.

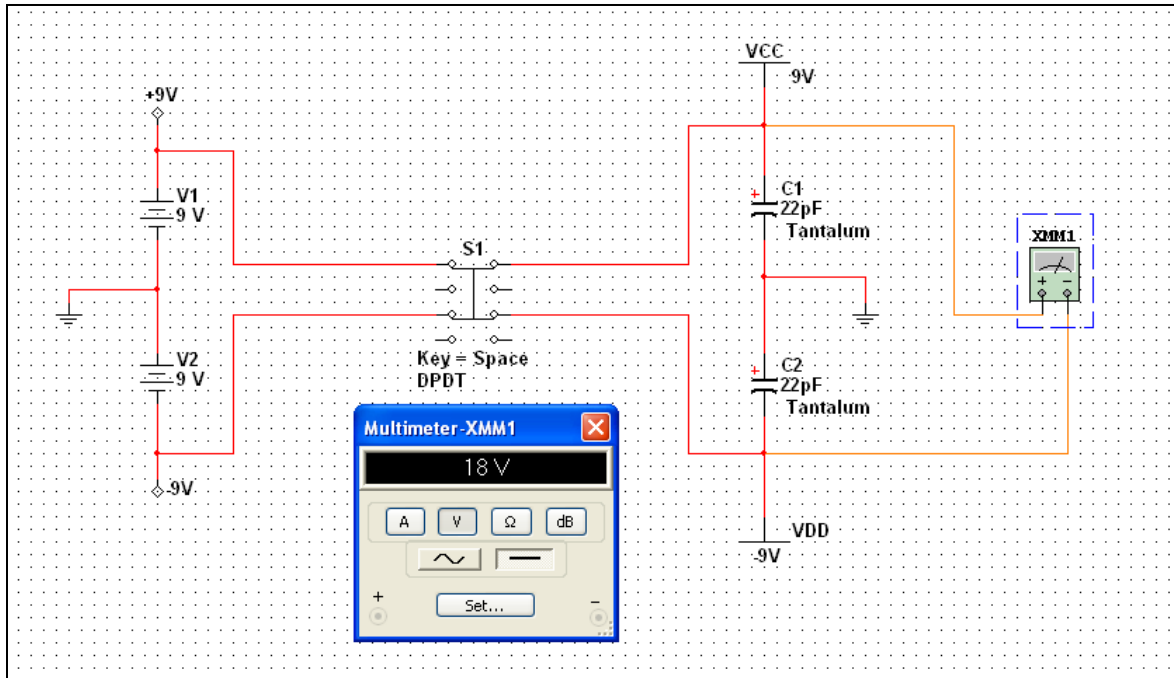


Figure 6. Power supply simulation using Multisim 11.0

The power supply circuit provides ± 12 V to the op amps. This was verified by protoboard testing using a BK Precision 1760A DC Power Supply and a Fluke 8808A 5-1/2 digital multimeter.

In Alternative Design 1, the power supply consisted of two 9 V batteries to provide an operating voltage range of ± 9 V. Testing methods were implemented in order to determine the battery life of the device, which must be at least 12 hours to accommodate for one night of sleep. A voltage level indicator was coded in embedded C to inform the user of battery life. A warning LED emitted when the battery life was below 12 hours, as well as a warning message in the LabVIEW program to inform the user of low battery. The code for the battery level indicator and other microcontroller functions are included in the Appendix of this report. It should be noted that the code may not compile due to formatting issues with this report.

2.1.2.3 Electrodes

Electrical potentials from the four muscles of mastication were be acquired from nine Ag-AgCl surface electrodes. Each muscle requires two electrodes, one electrode for positive and one electrode for negative. An additional electrode must be used as a reference electrode to provide adequate grounding.

Reusable electrodes were initially considered because they improve the comfort and simplicity of the device. They can potentially be removable from the device so that the fabric may be washed, and they can also be easily replaced if they

fail. The first consideration for a reusable electrode was the E272-LS SLIM-TRODE manufactured by In Vivo Metric (Healdsburg, CA), shown in FIG.7.



Figure 7. In Vivo Metric's reusable Ag-AgCl electrodes

These particular electrodes are designed for applications requiring lightweight and smaller electrodes. They may be applied to the skin with or without electrode gel, but for our purposes, they were applied without gel. The lead wires are strong, flexible, and fatigue resistant, providing for long life and sustainability. The results of reusable electrodes are shown in FIG. 8.

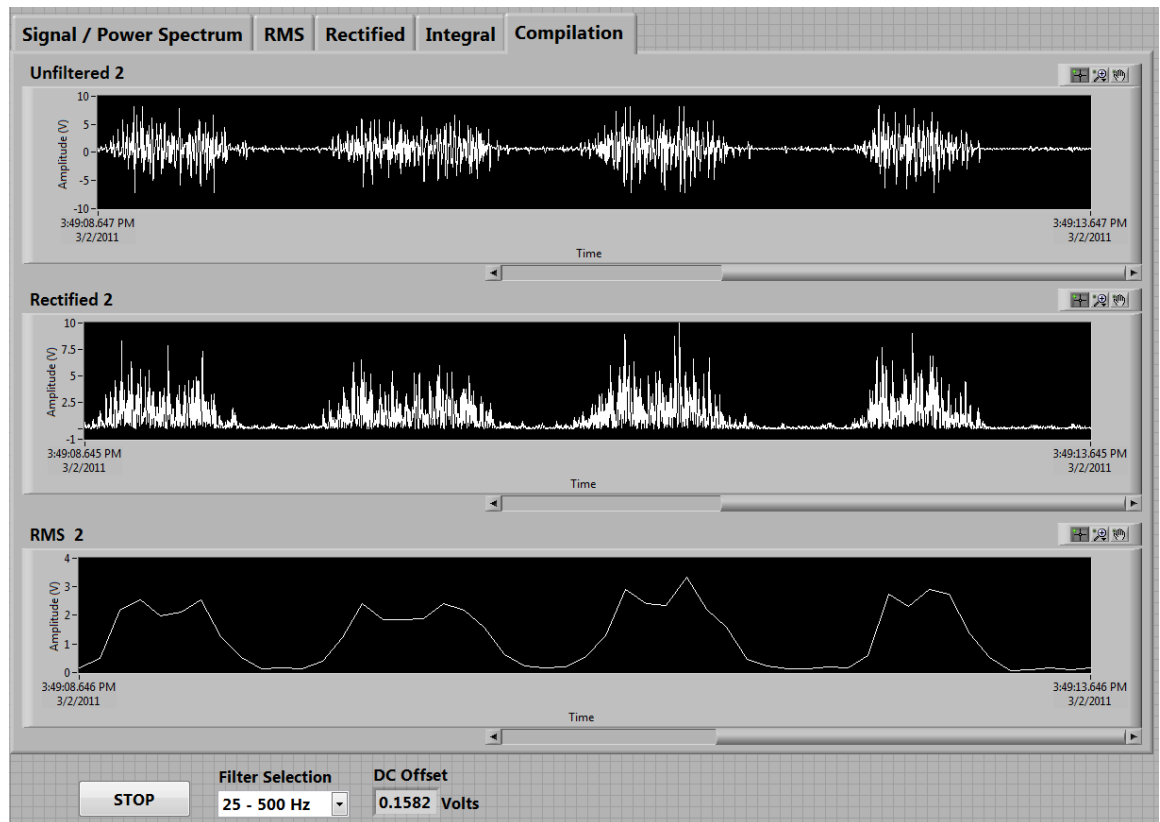


Figure 8. Reusable electrode test

It can be seen from FIG. 9. that the signal quality of the reusable electrodes is excellent and reproducible. However, they were difficult to maintain adhesion to the skin for extensive periods of time, and for this reason, they were removed from the final product design.

Alternatively, disposable surface electrodes were implemented in the final product due to their superior adhesion and improved signal quality. Kendall / Tyco

ARBO 24 mm surface EMG electrodes were utilized in the final design, however, any electrode with a snap connection may be substituted. The disposable electrodes are shown in FIG. 9.



Figure 9. Kendall / Tyco ARBO surface EMG electrodes

These electrodes have a unique, patented pre-gelled adhesive side with non-irritating gel, especially developed to prevent allergic reactions. They are latex free and therefore suitable for every skin type. The snap-on connector can easily be pushed on or removed from the electrode lead, resulting in optimal user friendliness. The gel adhesive is not greasy compared to other electrode gels, and maintains incredible adhesion despite rigorous stress and strain tests.

The electrode circuitry is shown in Fig. 10.

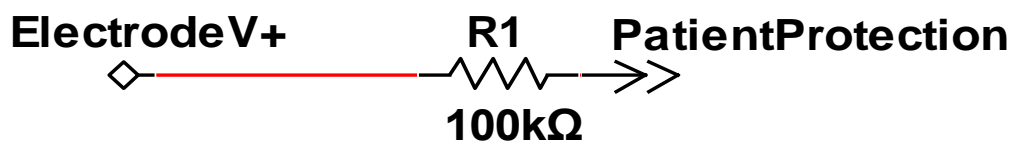


Figure 10. Electrode input circuitry

The 100 kΩ resistor increases the input resistance, which is desirable for biopotential amplifiers. Patient protection circuitry follows the 100 kΩ resistor to ensure that both the patient and the circuit components are protected.

2.1.2.4 Patient Protection

A major safety concern is that of electrical shock to the patient. Since the patient will have electrodes attached to them with potentially harmful voltages during long periods of unconsciousness, protection from electrical shock is of vital importance.

Silicon diodes offer excellent protection to patients by conducting current when the voltage exceeds 700 mV (forward-biased) . The diode protection circuitry is shown in Fig. 11.

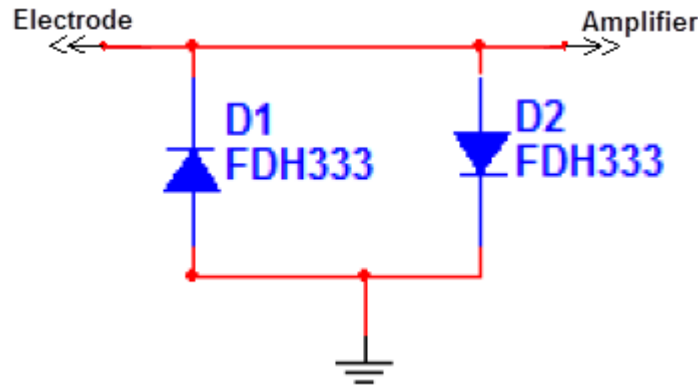


Figure 11. Patient protection circuitry

FDH333 high-conductance, low-leakage diodes were utilized due to their low reverse current when they are forward biased. This ensures that maximum current is shorted to ground when a large voltage potential exists across the diodes. The FDH333 diodes were tested and successfully shorted the current to ground when the voltage exceeded ~ 600 mV. Thus, this configuration provides good electrical protection for the patient's safety.

Another method for electrical shock protection is the use of the AC-DC wall transformer, providing isolation from the patient and the AC wall voltage. Since there is no galvanic connection between the patient and the wall, current cannot flow directly from the wall to the patient. The cautious user should, however, always plug the TMD Diagnostics System into a surge protector to ensure that no electrical surge damages the components and cause potentially harmful current to pass to the patient.

The reader should note that EMG signals typically do not exceed 90 mV, however it is important to protect the patient regardless. The diode circuit and wall transformer design is inexpensive and easy to implement into the circuit and therefore should always be included in future applications. The patient should be rest assured that they are entirely protected from electric shock.

2.1.2.5 Instrumentation Amplifier

A biopotential amplifier has several requirements, including high input impedance (typically > 10 GΩ), low output impedance, and a high CMRR (typically > 100 dB). A three op amp instrumentation amplifier encompasses all of these parameters and was selected as the optimal amplifier design.

The AD620 instrumentation amplifier (IA) from Analog Devices was selected because it is a low cost, high accuracy instrumentation amplifier with gains from 1 to 10,000 set by one external resistor. Its low noise, low input bias current, and low power makes it ideal for medical applications such as electromyography. Its low power also makes it well-suited for battery operation. The instrumentation amplification circuitry is shown in Fig. 12.

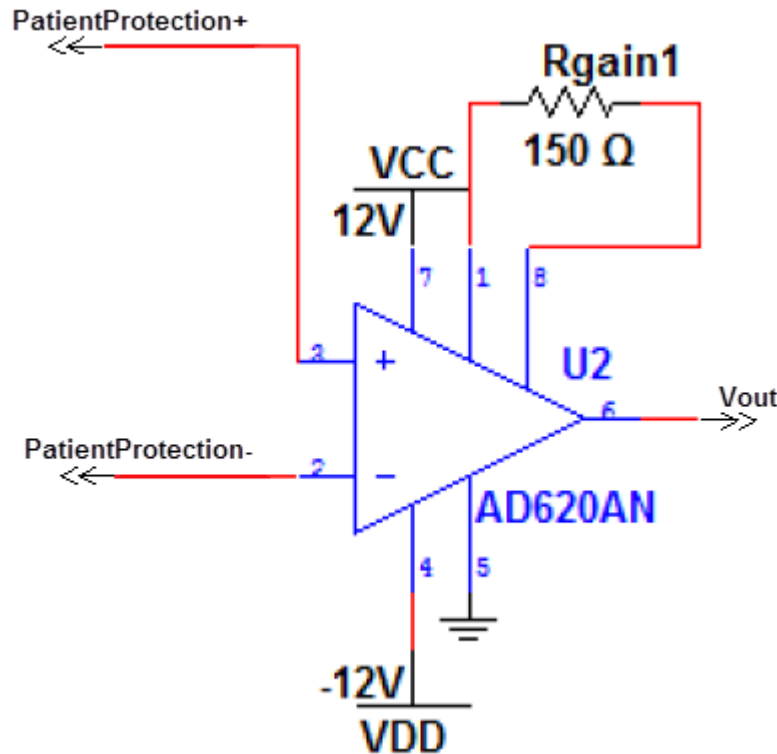


Figure 12. Instrumentation amplifier utilizing the AD620

The op amp is configured as a differential amplifier to amplify only the difference between the positive and negative electrodes. A 1N4001 diode is placed in series with the components positive power supply to ensure maximal protection of the op amp. This will eliminate the possibility of reversing the power supply, potentially damaging the component.

A gain of 330 was selected using a resistor of 150 Ω connected between pins 1 and 8 of the op amp. The gain equation was obtained from the AD620 datasheet and is given as

$$G = \frac{49.4 \text{ k}\Omega}{R_G} + 1. \quad (1)$$

Rearranging,

$$R_G = \frac{49.4 \text{ k}\Omega}{G-1} \quad (2)$$

The amplification of the AD620 with a gain of 1000 is shown in Fig. 13.

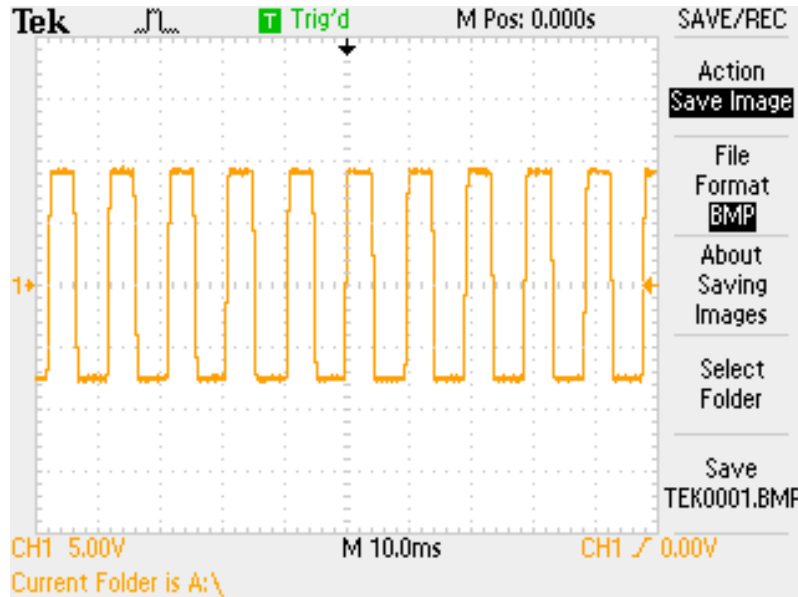


Figure 13. Amplification of the AD620 instrumentation amplifier with gain of 1000

This output was taken from a Tektronix TDS 2024B oscilloscope. The output voltage was obtained from pin 6 of the AD620 following the coupling capacitor (to remove the DC offset). The input signal was a 200 Hz sinusoid waveform from a BK Precision 4011A function generator at a peak to peak voltage in the millivolt range. Fig. 11 shows that the AD620 amplifies the voltage to about 9 V, where it becomes saturated. Due to this saturation, the gain of the instrumentation amplifier was reduced to 330 Ω to maintain the linear operating mode of the IA. The bandpass filter provides an additional amplification to the signal to ensure proper amplification.

2.1.2.6 Bandpass filter 25 Hz – 500 Hz

The frequency range of EMG from facial muscles is approximately 25 Hz to 500 Hz. Filters were implemented into the circuit in order to attenuate frequencies outside of this range. Fourth-order Butterworth cascading lowpass and highpass active filters were initially because they only require two op amps and minimal external components. The filters were designed using Microchip's Filterlab software to design the Butterworth, saving a significant amount of time. Some of the resistor and capacitor values were altered slightly so that realistic components could be ordered. The lowpass filter is shown in Fig. 14.

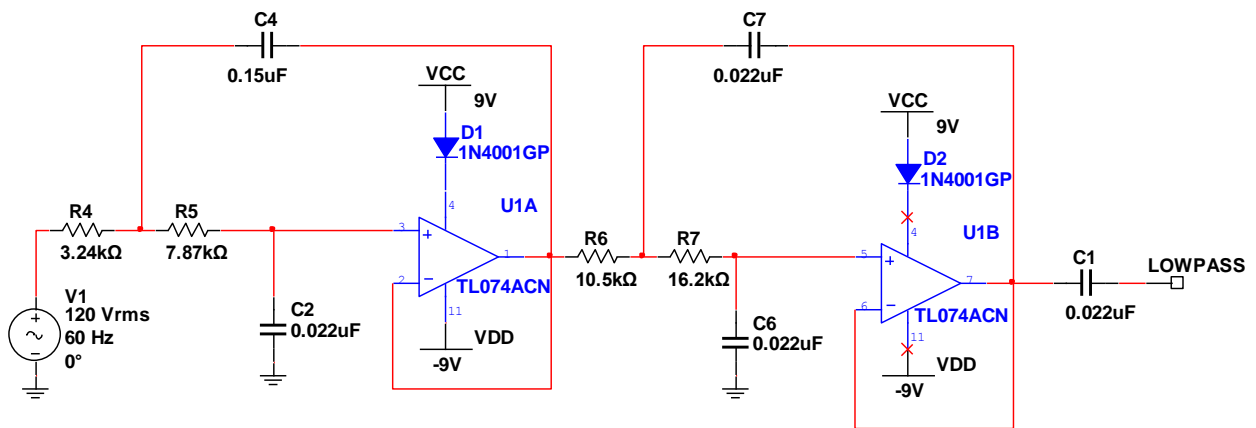


Figure 14. Fourth-order lowpass Butterworth filter with cutoff frequency 500 Hz

The cutoff frequency of this filter is 500 Hz to ensure that frequencies below the -3 dB passband are attenuated. TL074 quad op amps were selected due to their low noise and distortion. They are also cost effective and will save space on the PCB due to their quad op amp package.

An AC simulation was performed using Multisim 11.0, as shown in Fig. 14.

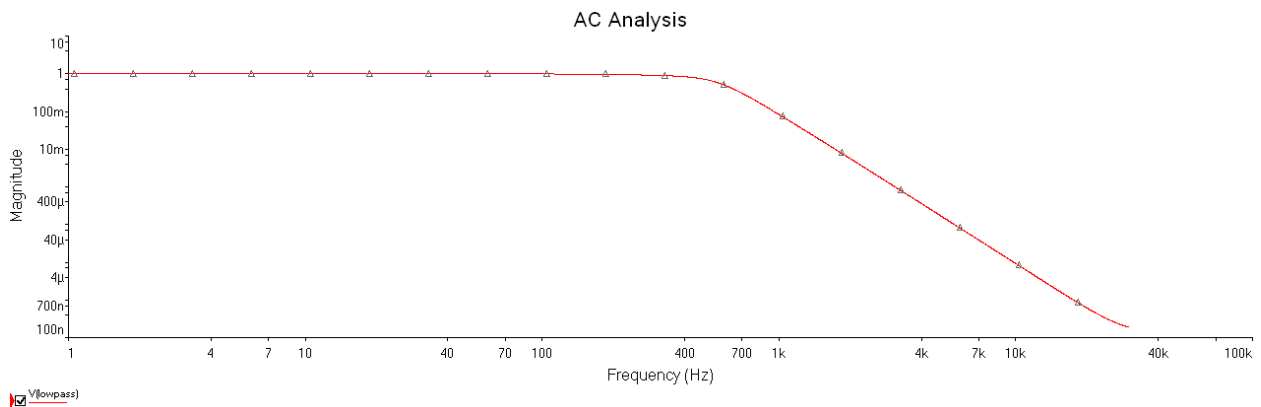


Figure 15. AC simulation for the lowpass filter

It is evident from Fig. 15 that the filter sufficiently attenuated frequencies above 500 Hz. Protoboard testing of the lowpass filter was conducted and it proved to sufficiently attenuate frequencies above 500 Hz.

The highpass filter is shown in Fig. 16.

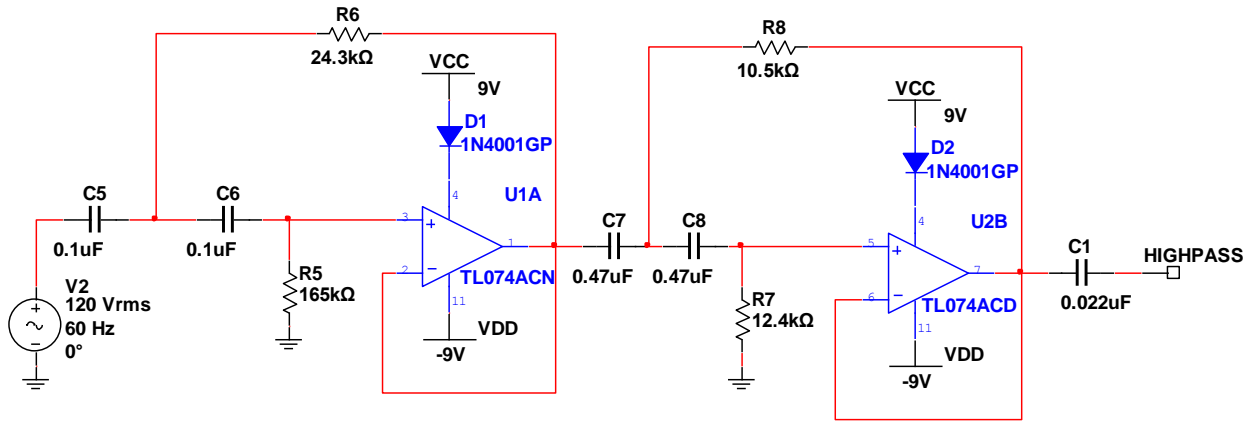


Figure 16. Fourth-order highpass filter with cutoff frequency 25 Hz

The cutoff frequency of this filter is 25 Hz to ensure that frequencies below the -3 dB passband are attenuated. Once again, the TL074 quad op amps were utilized in the design.

An AC simulation was performed using Multisim 11.0, as shown in Fig. 17.

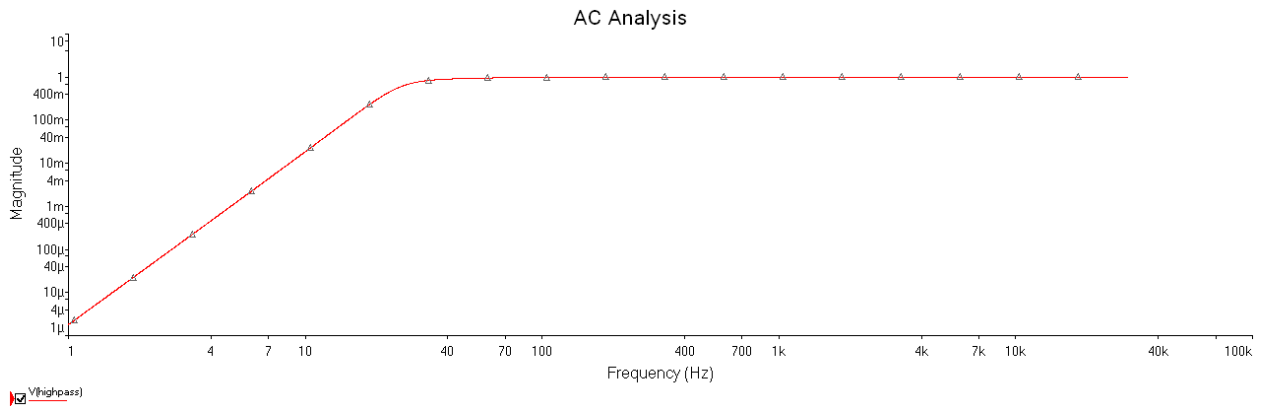


Figure 17. AC simulation for the highpass filter

It is evident from Fig. 17 that the filter sufficiently attenuated frequencies below 25 Hz. Protoboard testing of the lowpass filter was conducted and it proved to sufficiently attenuate frequencies below 25 Hz.

The lowpass and highpass filters were connected in the physical circuit for protoboard testing using the TL074 JFET quad operational amplifier. The results are shown in FIGS. 18, 19, 20, and 21.

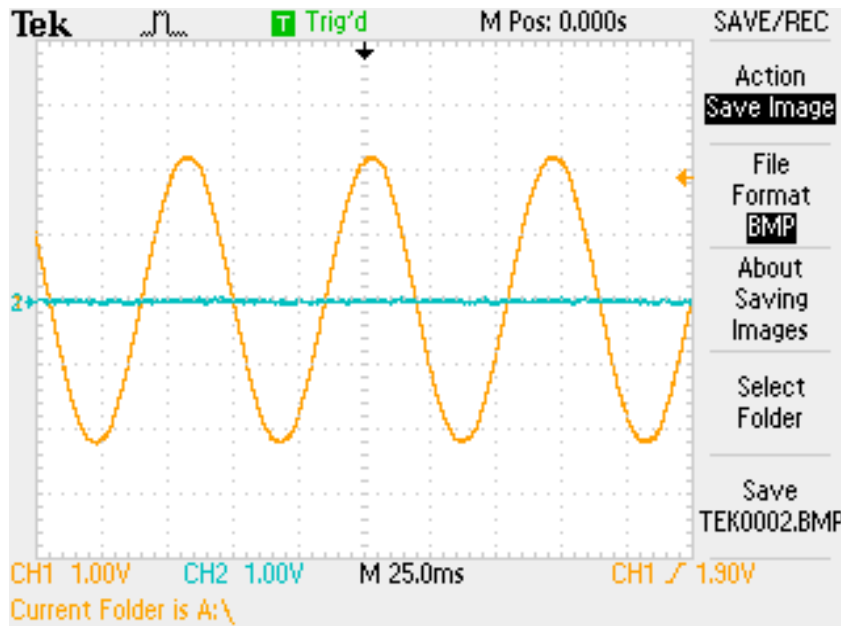


Figure 18. Bandpass filter at 15 Hz

It is evident from Fig. 18 that the bandpass filter sufficiently attenuated low frequencies. The input signal was 4.44 V pk-pk at 15 Hz. The output signal was 120 mV pk-pk, resulting in a gain of 0.027. This filtration was sufficient to meet our needs.

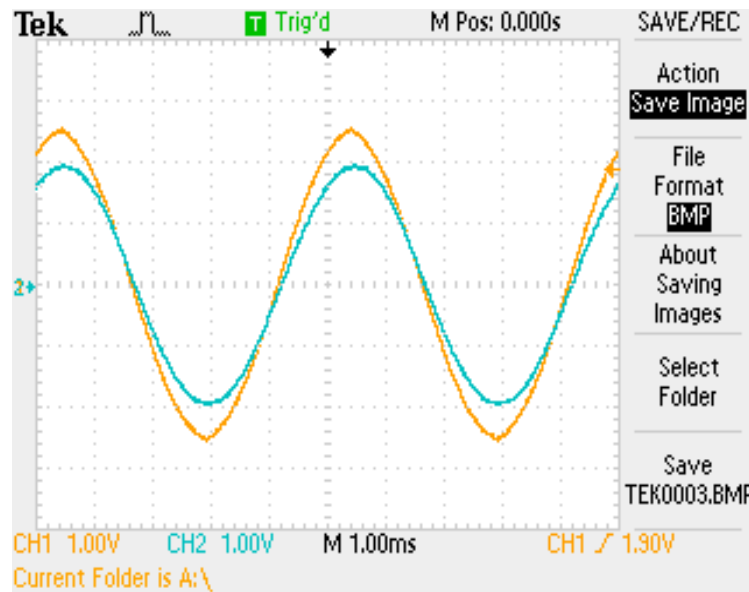


Figure 19. Bandpass filter at 200 Hz

It is evident from Fig. 19 that the bandpass filter sufficiently passed middle frequencies. The input signal was 5.08 V pk-pk at 200 Hz. The output signal was 3.92 V pk-pk, resulting in a gain of 0.772. Thus, the bandpass filter sufficiently passed

middle frequencies, which is important because 200 Hz frequencies are within the bandpass of EMG signals.

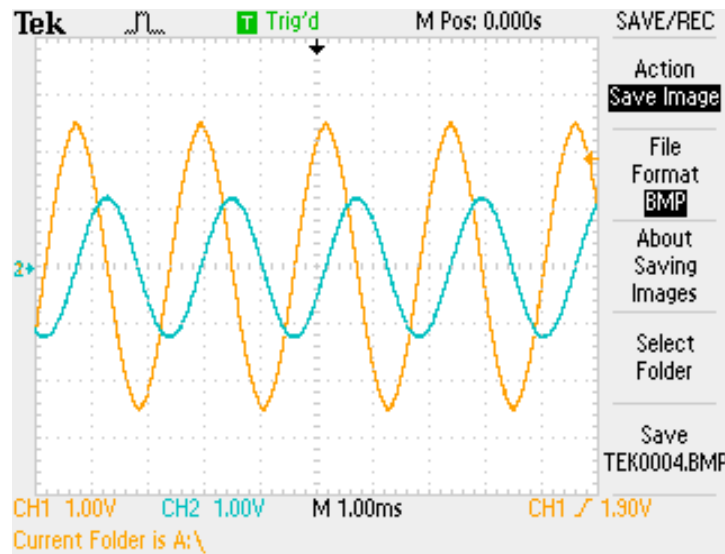


Figure 20. Bandpass filter at 450 Hz

It is evident from Fig. 20 that the bandpass filter sufficiently passed upper-middle frequencies. The input signal was 5.08 V pk-pk at 200 Hz. The output signal was 2.48 V pk-pk, resulting in a gain of 0.488. Thus, the bandpass filter sufficiently passed upper-middle frequencies, which is important because 450 Hz frequencies are at the upper end of the bandpass of EMG signals. The attenuation at 450 Hz compared to 200 Hz is due to the fact that the cutoff of the filter is at 500 Hz, so the filter begins attenuating frequencies just below 500 Hz.

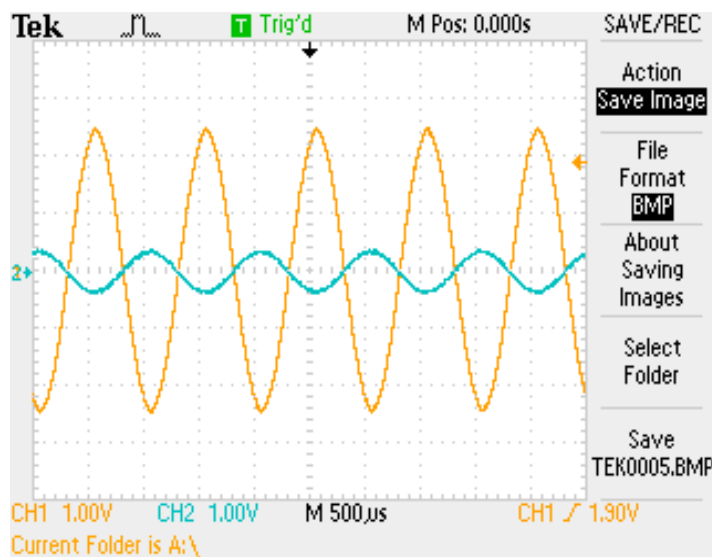


Figure 21. Bandpass filter at 1 kHz

It is evident from Fig. 21 that the bandpass filter sufficiently attenuated high frequencies as well. The input signal was 5.04 V pk-pk at 1 kHz. The output signal was 760 mV pk-pk, resulting in a gain of 0.151. This filtration was sufficient to meet our needs.

The cascaded highpass and lowpass filters were sufficient for filtration, but they take up more space on the PCB and require additional components. Additionally, there was too much current consumption for the four quad amplifiers to be considered for battery applications. Therefore, the cascaded filters were substituted with a simpler bandpass filter that reduced power consumption by 75%. Unexpectedly, the new bandpass filter design actually improved the signal quality, which is likely due to reduced thermal noise from a reduced external component count. The improved bandpass filter design is shown in FIG. 22.

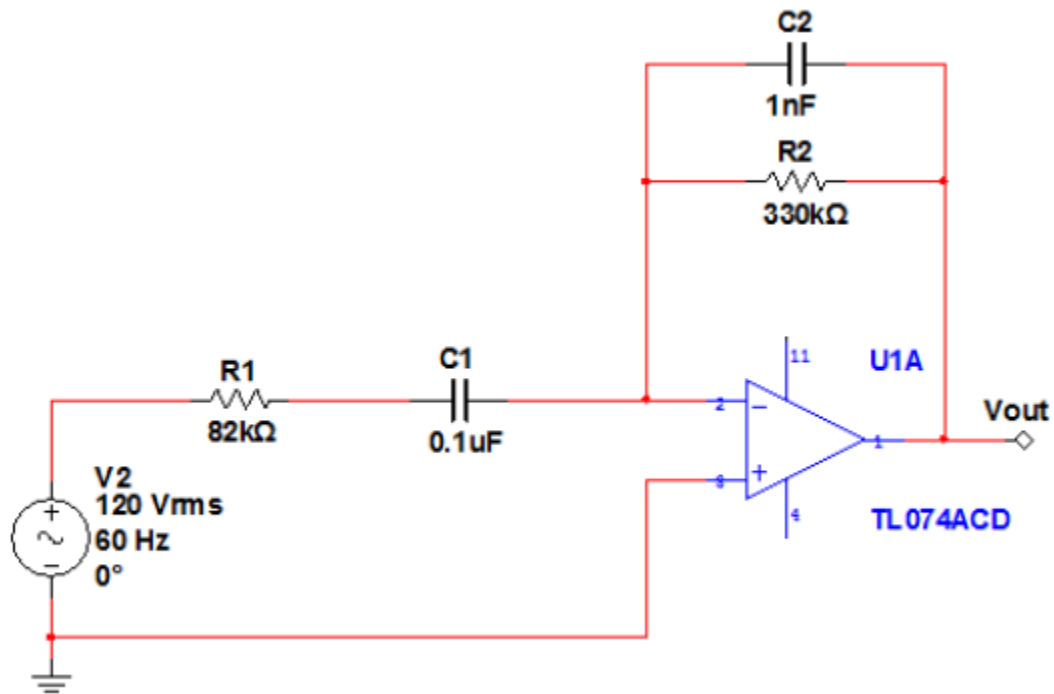


Figure 22. Improved bandpass filter design offering 75% power reduction, reduced external component count, and improved signal quality due to reduced resistor thermal noise

Protoboard testing of the improved bandpass filter design was conducted with a sinusoidal input and protocol similar to the above methods, but is omitted from this report due to length considerations.

2.1.2.7 60 Hz Notch Filter

A filter is necessary to remove power line frequency and ambient noise at 60 Hz. Since 60 Hz is within the bandwidth of electromyography signals, a notch filter must be implemented to only attenuate frequencies in the 60 Hz range. The notch filter is shown in Fig. 23.

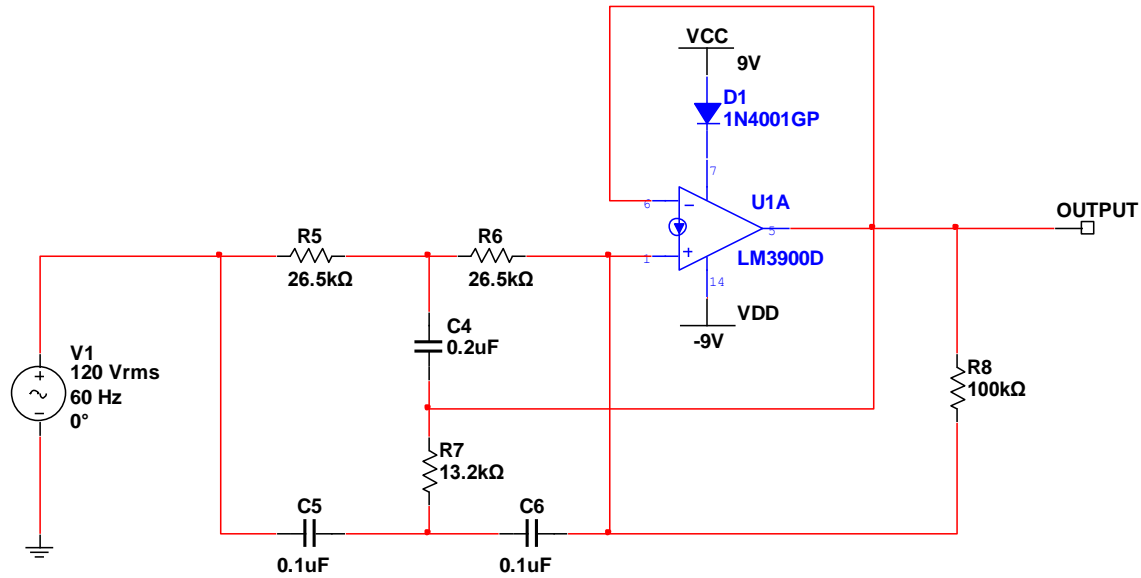


Figure 23. 60 Hz notch filter

This filter is a derivative of the Twin T notch filter design. This was selected because it has a high Q factor and an infinitely deep notch. The LM3900 from Texas Instruments was selected due to its excellent performance characteristics shown in Multisim 11.0. The AC simulation is shown in Fig. 24.

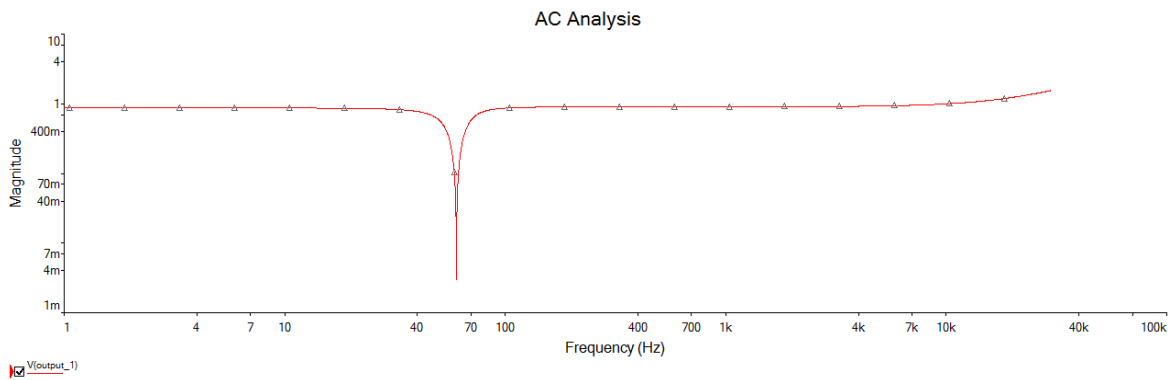


Figure 24. 60 Hz notch filter AC simulation

It is evident from Figure 24 that the filter sufficiently attenuates 60 Hz noise, while passing nearby frequencies.

Protoboard testing was conducted on the 60 Hz notch filter and the results are shown in Fig. 25.

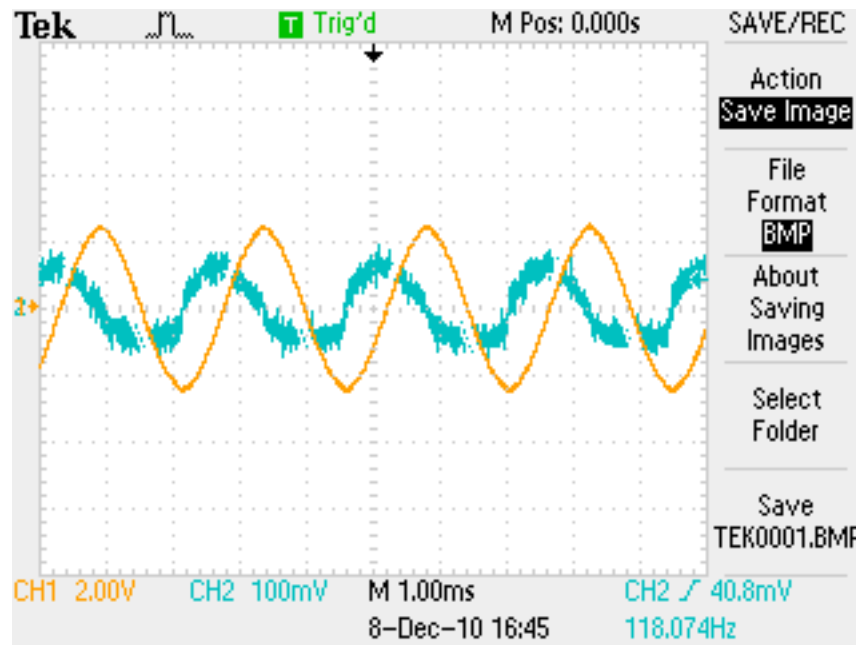


Figure 25. *Protoboard testing of the 60 Hz notch filter*

It is apparent from Fig. 25 that the output signal, shown in blue, is distorted and noisy. The input signal was 5.0 V pk-pk at a frequency of 120 Hz. The output signal was approximately 200 mV pk-pk, resulting in a gain of 0.04. Thus, the filter significantly attenuated a 120 Hz signal, which should not occur.

Additional testing of the notch filter was conducted using a TL074 op amp. The output resulted in no filtering at all, which was confirmed by a Multisim AC analysis. The AC simulation of the 60 Hz notch filter cannot be verified by Filterlab due to the restriction of building bandstop filters, but it may be necessary in the future to confirm the simulation with a program such as PSpice.

The 60 Hz notch filter was removed from the analog circuit and a 60 Hz notch filter was implemented into the LabVIEW program. This will likely be sufficient to meet EMG filtering standards, as the environment in which our product will be used will likely not have a significant amount of electromagnetic interference (EMI), and therefore digital filtration in LabVIEW is an acceptable means for filtration.

2.1.2.8 Microprocessor

If a microprocessor is used in future applications, it should be responsible for acquiring four muscle signals post-amplification and filtration, performing analog to digital conversion on the signals, multiplexing the four signals into one output, and then passing the data to a Bluetooth module by means of RX and TX. The microcontroller was attempted but was substituted due to time constraints. A description of the microcontroller progress will be discussed herein.

An ATmega644PA microcontroller from AVR was selected for use in this project. It is an 8-bit microcontroller with 64 Kbytes of Flash memory, 8 channels of 10 bit A/D single ended channels, all of which satisfy the requirements of the project. The ATmega644PA is shown in FIG. 26.

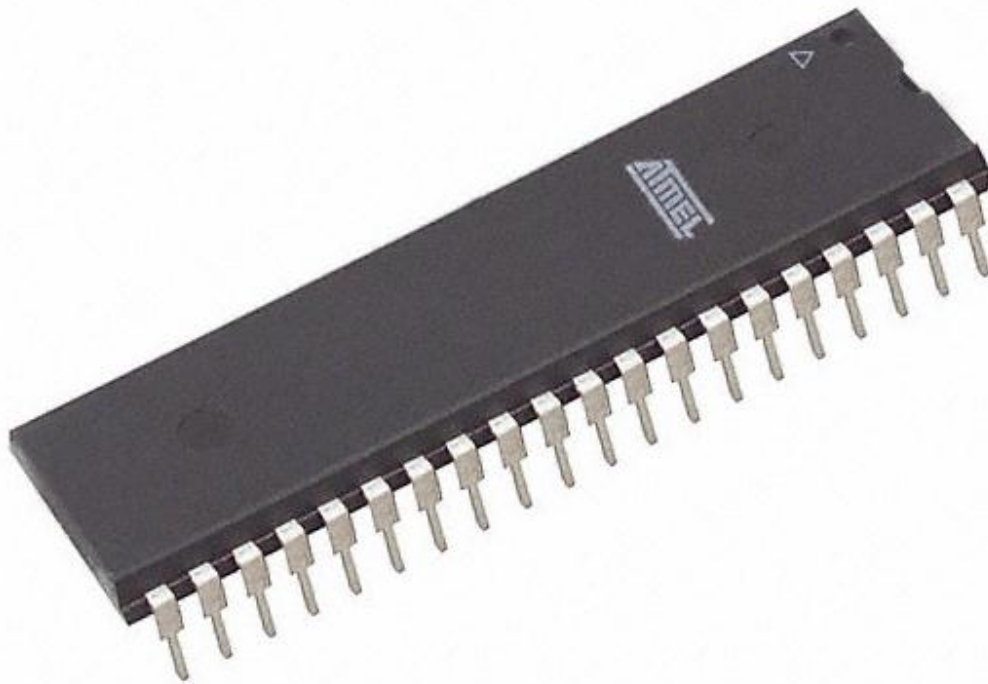


Figure 26. *ATmega644PA microcontroller*

Some code was written to perform analog to digital conversion (ADC) of the EMG signals well as inform the user of low battery status, both of which functioned correctly and are available for viewing in the Appendix of this report. The function “ReadADC” was used to convert the analog EMG signals to digital signals for the microcontroller. The function “BatteryLevelIndicator” was used to alert the user when the battery was low. This indicator was designed to work with a Red, Green LED so that when the battery power was sufficient to power the device, a green color would be emitted, low battery emitted a yellow color, and immediate replacement yielded a red color. A red color indicates that the device will not last much longer.

Time division multiplexing was selected to combine the four EMG signals into one output. Time-division multiplexing (TDM) is a type of digital in which two or more bit streams are transferred apparently simultaneously as sub-channels in one communication channel, but are physically taking turns on the channel. The function “SignalMultiplexer” in this appendix was the preliminary method to multiplex signals. Shift registers may also be considered in future applications.

2.1.2.9 Data Acquisition

To acquire data from the circuit and perform analog to digital conversion, the USB 6008 OEM from National Instruments was selected. It has 12 bit analog input resolution of 12 bits and has a maximum sampling rate of 10 kS/s, both of which satisfy the criteria of this project. Its maximum voltage range and minimum voltage accuracy are also suitable for EMG signal acquisition. The USB 6008 OEM is shown in FIG. 27.



Figure 27. USB 6008 OEM DAQ from National Instruments

The OEM model offers a low-cost alternative to data acquisition and USB interfaces to embedded designs. For the final product, it is contained within the circuit enclosure for ease of use for the patient.

The USB 6008 was tested extensively and it acquires data similar to higher model PXI DAQ devices and completely satisfied the data acquisition requirements for the project.

2.1.2.10 Protoboard testing

The test setup is shown in Fig. 28.

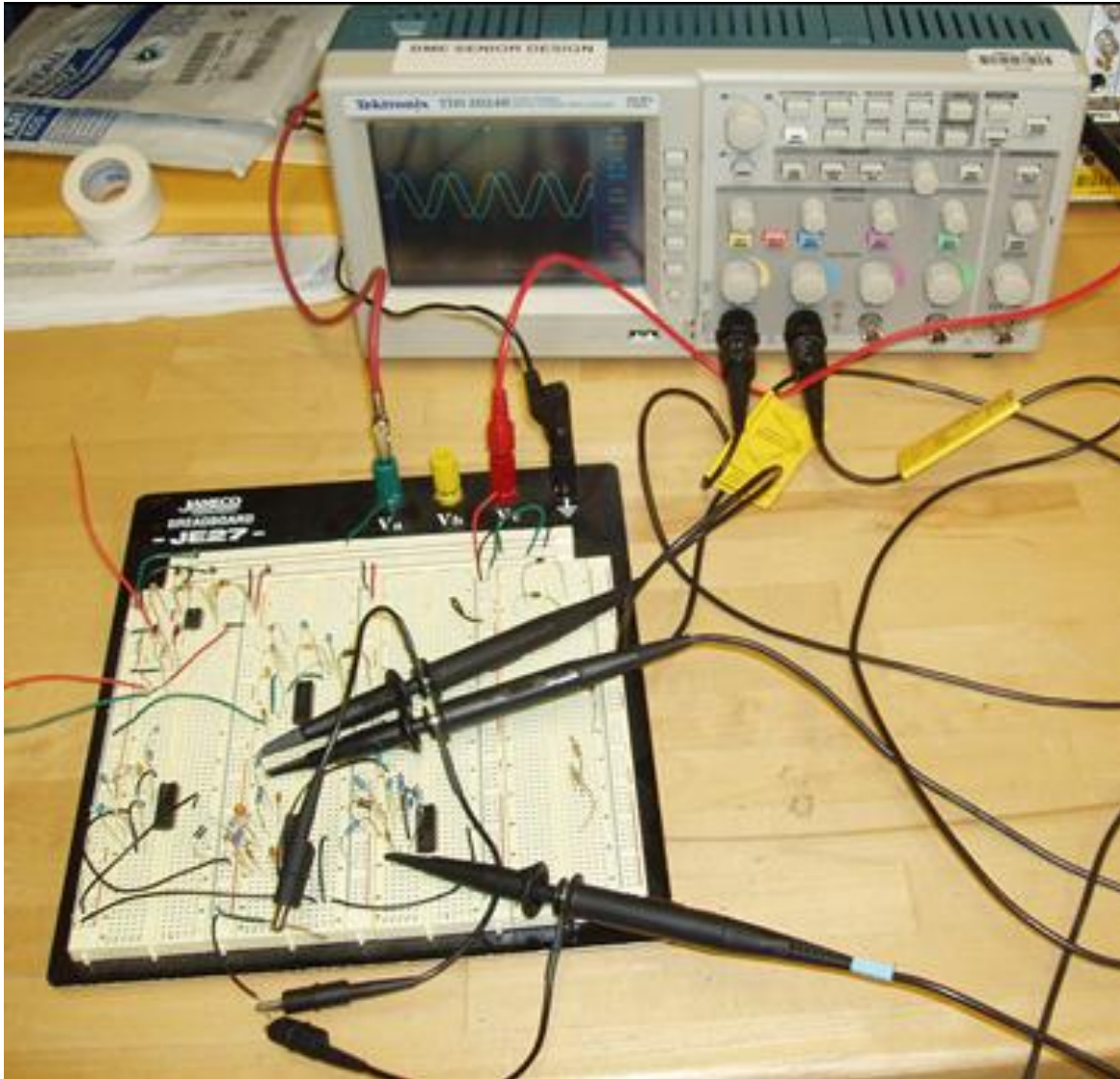


Figure 28. *Protoboard test setup*

Power was supplied to the circuit via a BK Precision 1760A DC power supply. A BK Precision 4011A 5MHz function generator was used to generate the sinusoidal input waveforms. A Tektronix TDS 2024B Four Channel digital storage oscilloscope was used to capture the input and output signals. A Fluke 8808A digital multimeter was used to test voltage and current levels throughout the circuit.

2.1.2.11 Bluetooth

Bluetooth is a wireless technology standard and was initially selected as the communication protocol of choice. Bluetooth allows for a wireless interface, significantly reducing the complexity of the device and making it user-friendly for set up and maintenance. Bluetooth modules can generally be powered from low voltage supplies and work excellent when powered by battery. The range can be anywhere up to 350 feet or more, which is desirable since the receiving laptop may

be across the user's room. A Bluetooth interface was attempted early in the semester but was substituted with a wired connection later in the semester due to time constraints. Future applications should consider employing Bluetooth due to its improvements over a wired connection.

The BlueSMiRF Gold Bluetooth module by SparkFun Electronics was selected due to its low cost (\$64.95) and RX/TX capabilities. It consumed a low amount of current (25 mA), featured an encrypted connection, had a range of 350 feet, and could be operated by a single power supply of 3.3 – 6 V. The BlueSMiRF module is shown in FIG. 29.



Figure 29. *BlueSMiRF Bluetooth module from SparkFun Electronics*

A Bluetooth USB dongle (AZiO BTD-V201 USB 2.0 Micro Bluetooth Adapter) was ordered to interface with any laptop. By using this device, any computer equipped with the TMD Diagnostics System Application could be used to acquire data provided that the computer met the specifications. The USB dongle is shown in FIG. 30.



Figure 30. *USB Bluetooth dongle for adaptation to nearly any personal computer*

Some code (Embedded C) was attempted to establish a Bluetooth connection. This code was designed for use on a Microchip microcontroller but can be modified to operate with any library file, such as AVR. This code is included in the Appendix of this report and may be used by anyone without the consent of the authors.

2.1.2.12 Neuroband Data Acquisition Unit

The Neuroband device for housing the electrode snap leads was extensively modified to place snaps over the proper muscles. The device houses 9 electrode snap leads, two per muscle being analyzed and one on the forehead as a ground. The attachment ends are all located on one side of the device to make the connection to the enclosure easy. The prototype is fully adjustable to all head sizes. The device is shown in FIG 31.



Figure 31. Modified Neuroband device housing the snap electrode leads with lead ends coming out of one side

2.1.2.13 Computer

The laptop Dell Latitude E6410 (FIG. 32) was decided upon by the University of Connecticut Health Center's IT department and is used to run the executable LabVIEW file.

The Dell E6410 is equipped with Windows 7, Intel Dual Core vPro 2.80 GHz processor, 4 GB RAM, 500 GB hard drive and a 14.1 inches Widescreen.

The computer receives the electromyographic data from the circuit via the National Instruments' USB 6008 OEM. Since the computer and the program will be running overnight, saving and processing a large amount of data, the 500 GB hard drive is optimal for this application.



Figure 32. *The Dell Latitude E6410*

2.1.2.14 LabVIEW program

An executable file contains a LabVIEW program that runs in the laptop. It acquires the data through the DAQ Assistant and splits the signals into the four different muscles for analysis.

Before handing the device to the patient, the clinician selects the thresholds above which he desires EMG data to be saved. The patient will be in charge of clicking a Start button located under the “EMG Acquisition” tab in order to begin data acquisition. A green light will indicate that data acquisition has begun. When the signal of a muscle exceeds a threshold preselected by the clinician, indicating relevant muscle activity, a portion of the signal is written to the file corresponding to that specific muscle. This way, we save memory by not storing data when bruxism events are not present. The Stop button will end the data acquisition.

When the patient returns the device to the clinician, he is able to view the EMG data saved. The clinician can select a muscle through the different tabs. Using a path control, the clinician selects which muscle’s activity he wants to view and of what date. There is also the option to adjust the speed at which the data is displayed. Moreover, a scrollbar allows the clinician to scroll over the data.

Fig 33 displays the flow charts that describe the functionality of the LabVIEW code.

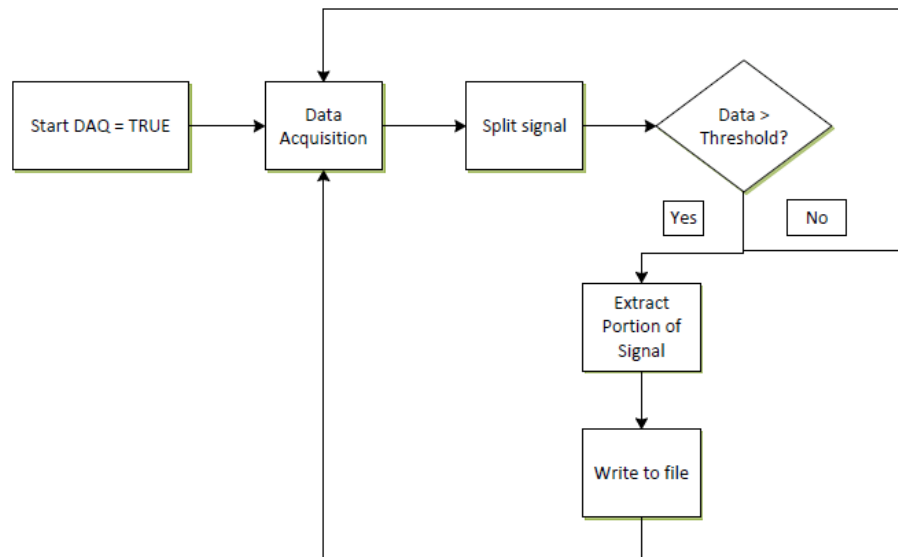


Fig 33. LabVIEW program flowchart for data acquisition

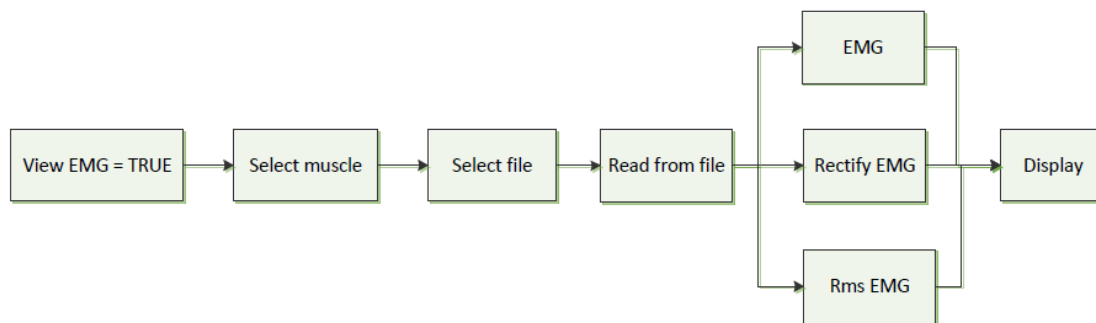


Fig 34. LabVIEW program flowchart for data display

2.2 Prototype

The Temporomandibular Joint Disorder Diagnostics System employs electromyography on the facial muscles to detect bruxism events for the diagnosis of TMJD. The EMG signals are amplified and filtered by the circuit. The USB 6008 DAQ acquires the data from the circuit, converts it to a digital signal, and passes the data to the laptop equipped with LabVIEW software. The LabVIEW software then further processes the data and allows the user to see raw, rectified, and RMS voltage electromyographic data. The program also tabulates the raw data so that the clinician can view the amount of bruxing events per muscle, how long each muscle spent bruxing, and the exact times each muscle bruxed.

The circuit consists of protection circuitry to protect the patient from electric shock, an instrumentation amplifier to amplify the EMG signals from the μV range to usable potentials, a bandpass filter to remove undesired frequencies, and a data acquisition board to acquire and convert to digital signals. The circuit is discussed in detail in the “Subunits” section of this report.

The results of the electromyographic data tests are shown in FIG. 35.

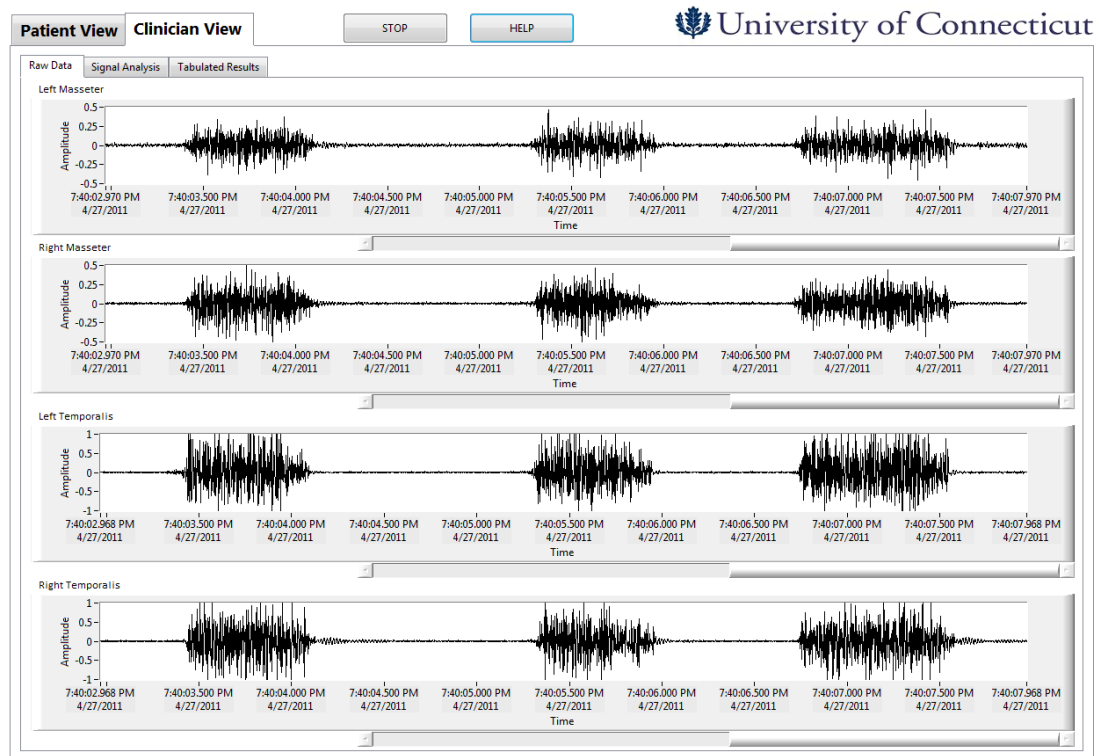


Figure 36. Electromyography data recorded from the TMJD Diagnostics System

FIG 35. Displays the raw EMG signals acquired from the four facial muscles. Per request of the client, the raw data is plotted as voltage amplitude versus time. The user may also view the signal analysis tab, which displays the rectified (FIG. 36) and RMS voltage (FIG. 37) signals.

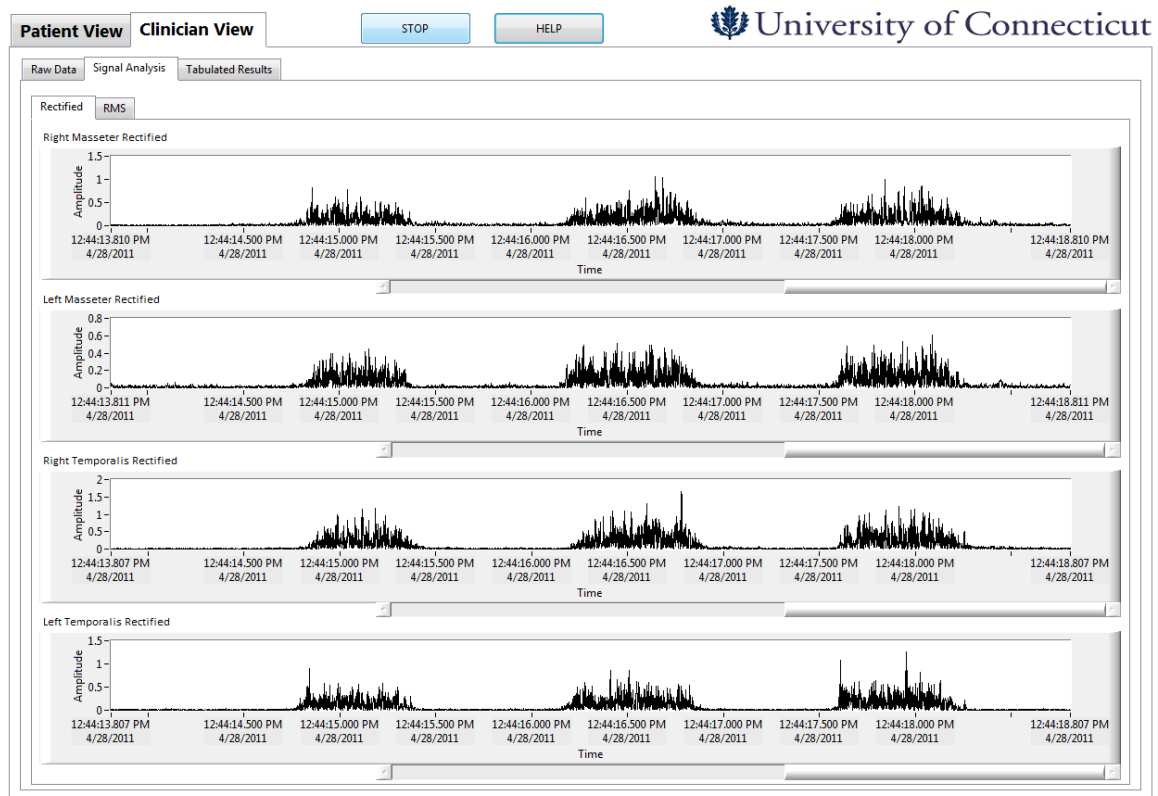


Figure 36. Rectified EMG signals

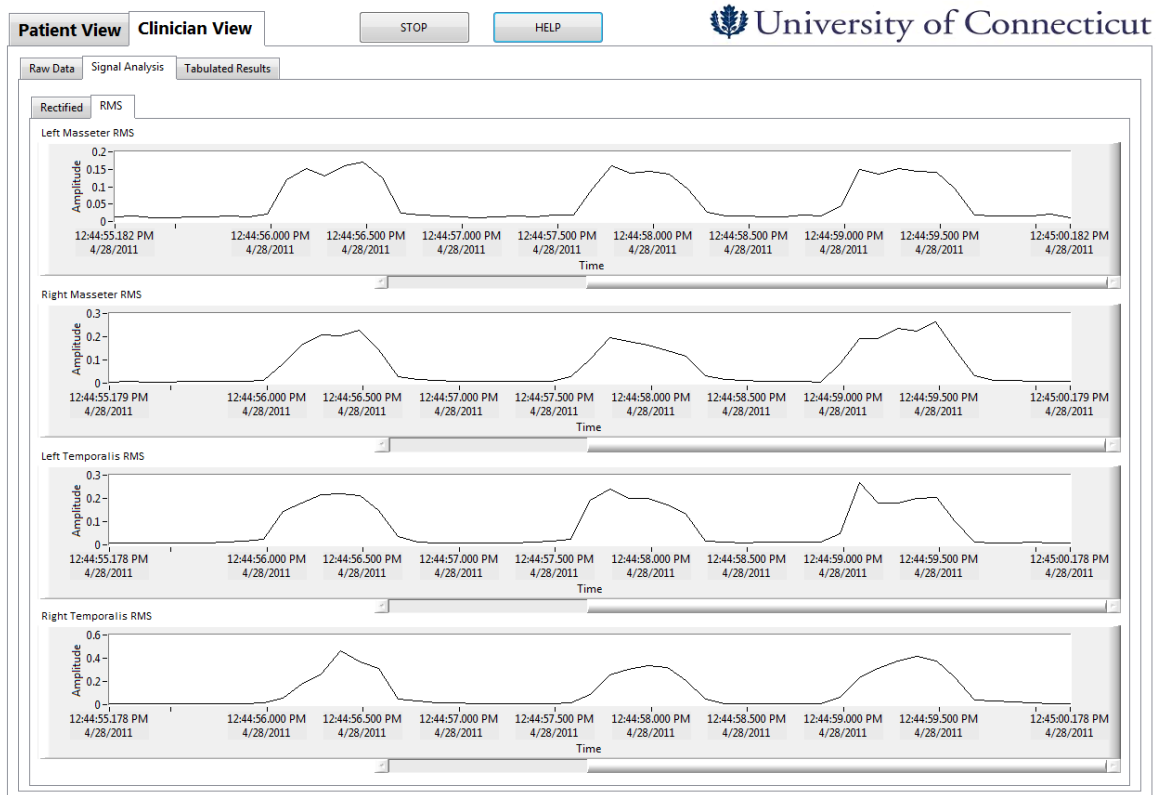


Figure 37. RMS voltage EMG signals

It can be seen from Figures 35, 36, and 37 that the TMJD Diagnostics System is capable of acquiring accurate EMG data. The system was tested over a period of six hours, and the EMG data was consistent with short term tests.

To simplify the diagnosis for clinicians, the raw EMG data is converted to tabular form to determine the number of bruxism events per muscle, the total time spent bruxing, and the exact times when the bruxing occurred. These results are shown in FIG. 38 for a test of two clenches.

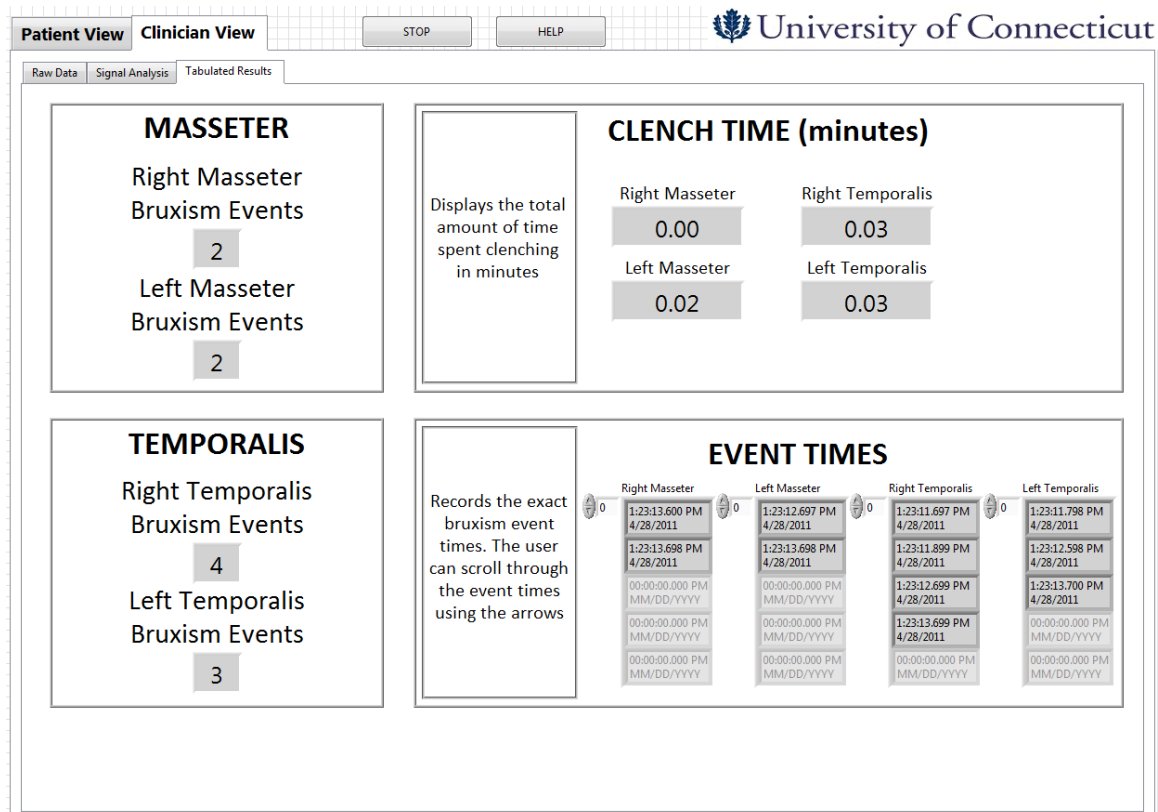


Figure 38. Tabulated data for easy diagnosis of bruxism

It can be seen that the results of the tabulated results are relatively accurate. This method will eliminate the need for the clinician to review hours of EMG data and count the number of bruxism events. The algorithm for detection is relatively simple, but improvements can be made to increase the accuracy of bruxism detection. The client has been provided with LabVIEW 2010 development software, so changes to the code can be performed in the future. The patient will not have access to the code because the application will be an executable file prohibiting any program changes.

Two members of this design project have Temporomandibular Joint Disorder, thus they were tested against the team member that did not have the disorder as a control. Tests were done over periods of 4 – 6 hours to ensure that data could be

collected over this extended period of time. The tests were successful as accurate EMG signals were obtained as well as accurate tabulated results.

The Neuroband Data Acquisition unit is made up of nine snap electrode leads and Dr. Diane's Neuroband©(FIG 39). The nine snap leads are organized over the four muscles associated with bruxism as well as over the forehead for ground.



Figure 39: Neuroband unit with snap electrode leads built in.

The leads of the Neuroband are organized by color for the muscle, and plug into the DIN ports to connect to the circuitry enclosure. These ports are labeled with a “Y” for yellow, “B” for blue, “G” for green, “R” for red, and a black dot for black.

LABVIEW PROTOTYPE DESCRIPTION

Two LabVIEW executable files were developed for data acquisition, storage, analysis and display.

The TMJD Diagnostics Application will be run by the patient before sleeping. The interface is user-friendly and instructions are provided at the start of the program, as shown in Figure 40. Additional help is also provided by clicking on the “Help” button located in the upper middle of the screen, as shown in Figure 41. A green light indicates that the program is running.

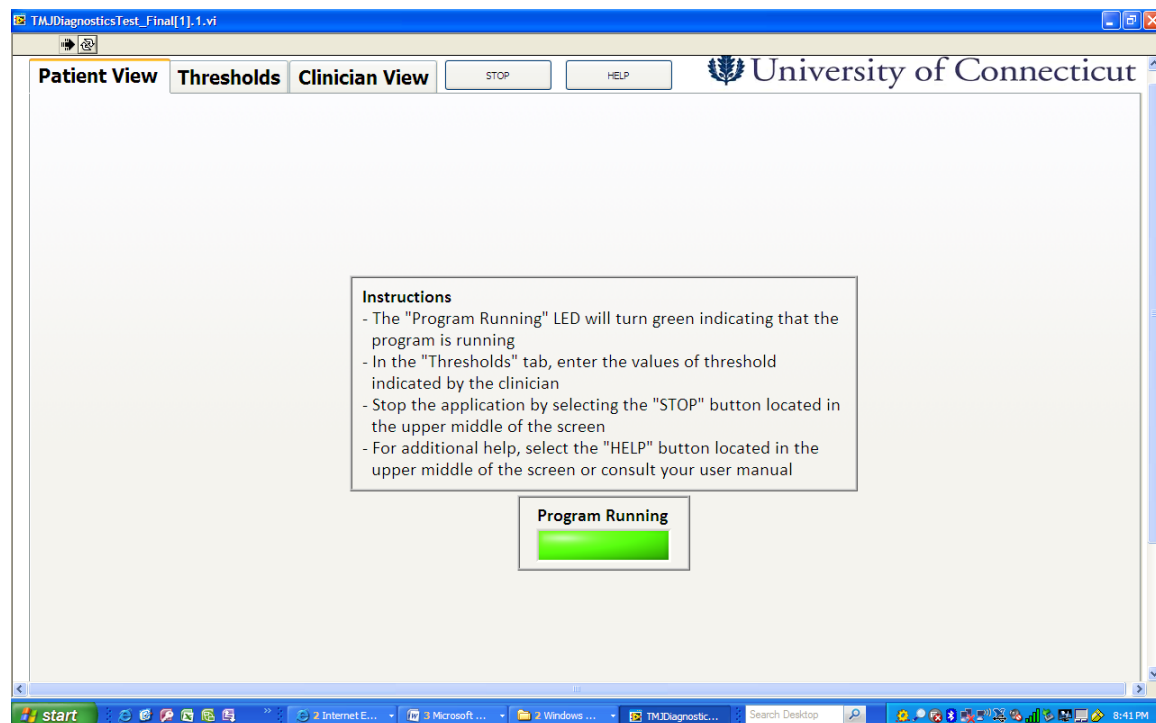


Figure 40. TMJD Diagnostics Application showing instructions and light indicating the program is running.

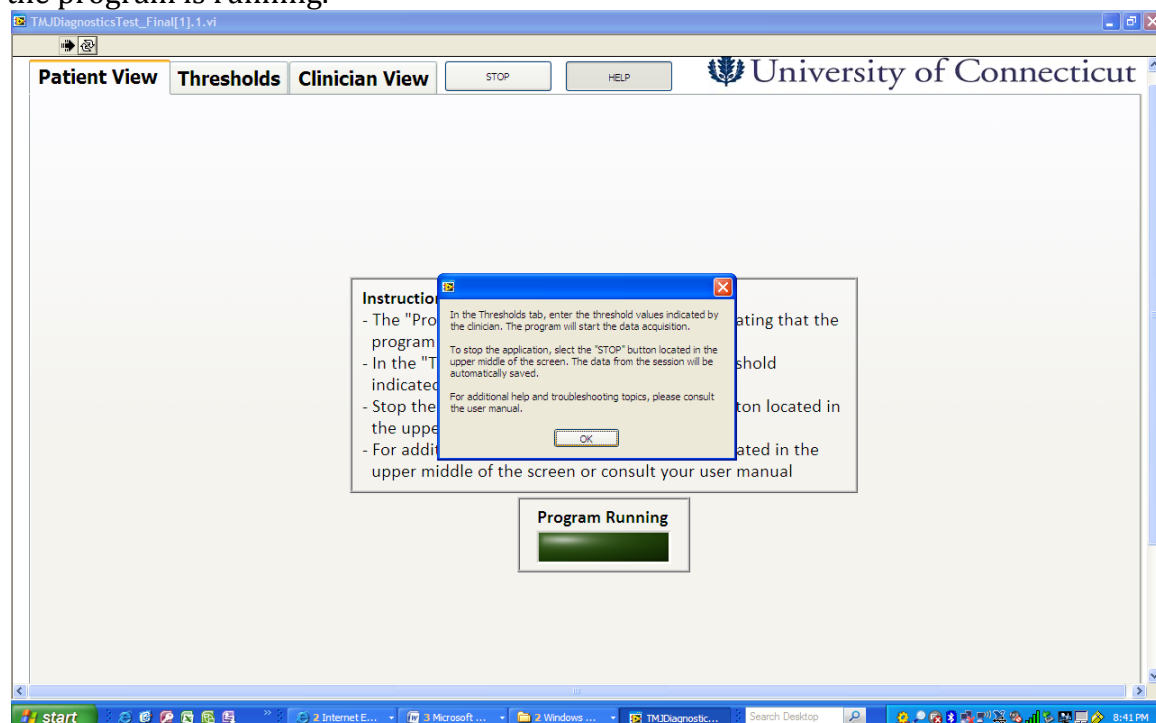


Figure 41. TMJD Diagnostics Application showing instructions and light indicating the program is running.

The patient will click on the "Thresholds" tab in order to enter the values of thresholds indicated previously by the clinician, as shown in Figure 42.

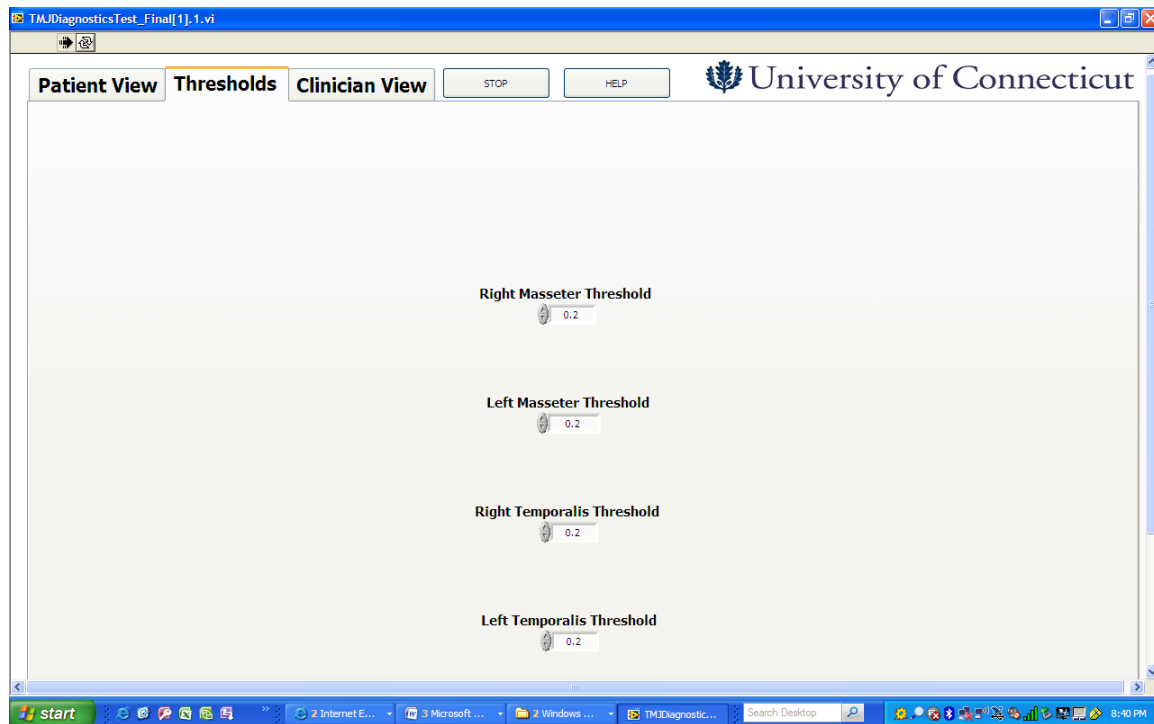


Figure 42. *Threshold tab of TMJD Diagnostics Application program for data acquisition*

At this point, data acquisition will begin and the patient should verify that signals are displayed on the Clinician View tab when clenching and grinding, as shown in Figure 43. After this verification, the patient can proceed to sleep. Data will be displayed in real time and acquired over the period of time until the patient awakens.

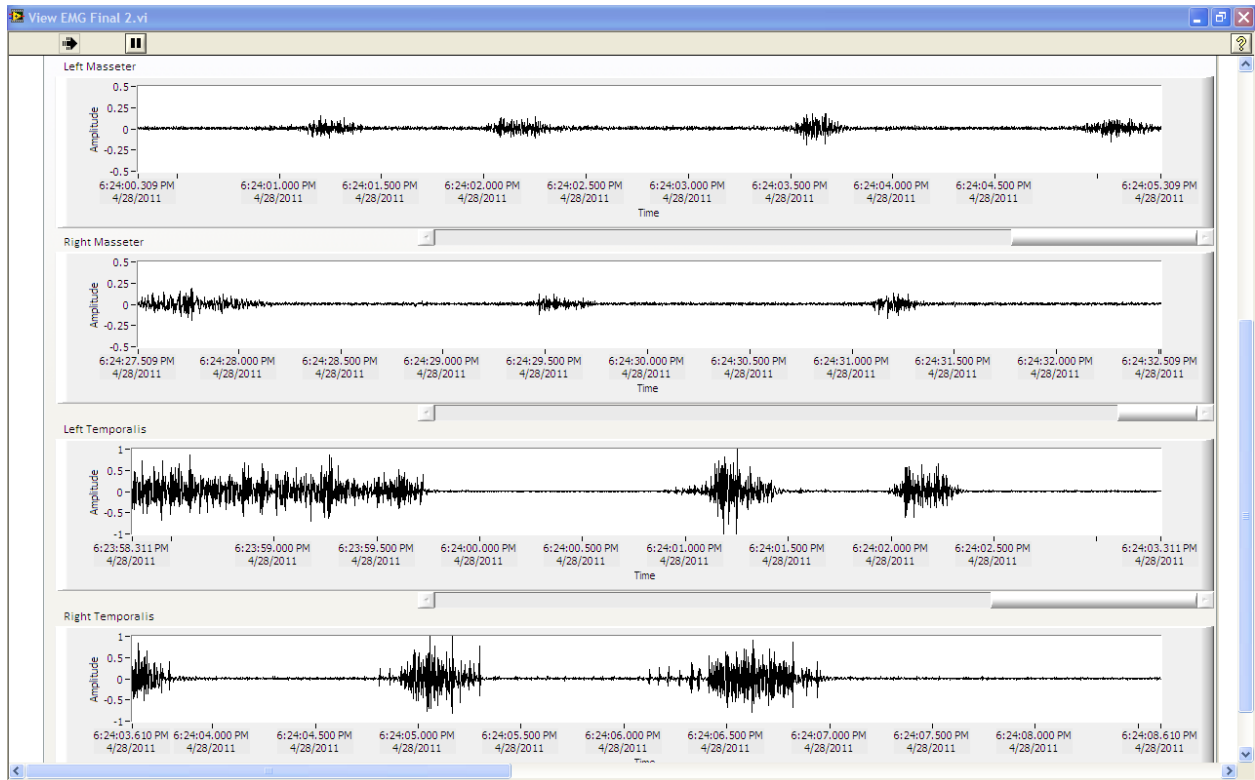


Figure 43. Clinician View tab of TMJD Diagnostics Application

After awaking, the patient stops the data acquisition by clicking the Stop button located in the upper middle of the screen.

A summary of the results can be viewed under the Tabulated results tab, shown in Figure 44, showing total number of bruxing events of each muscle, total duration of the events and the exact times of these events.

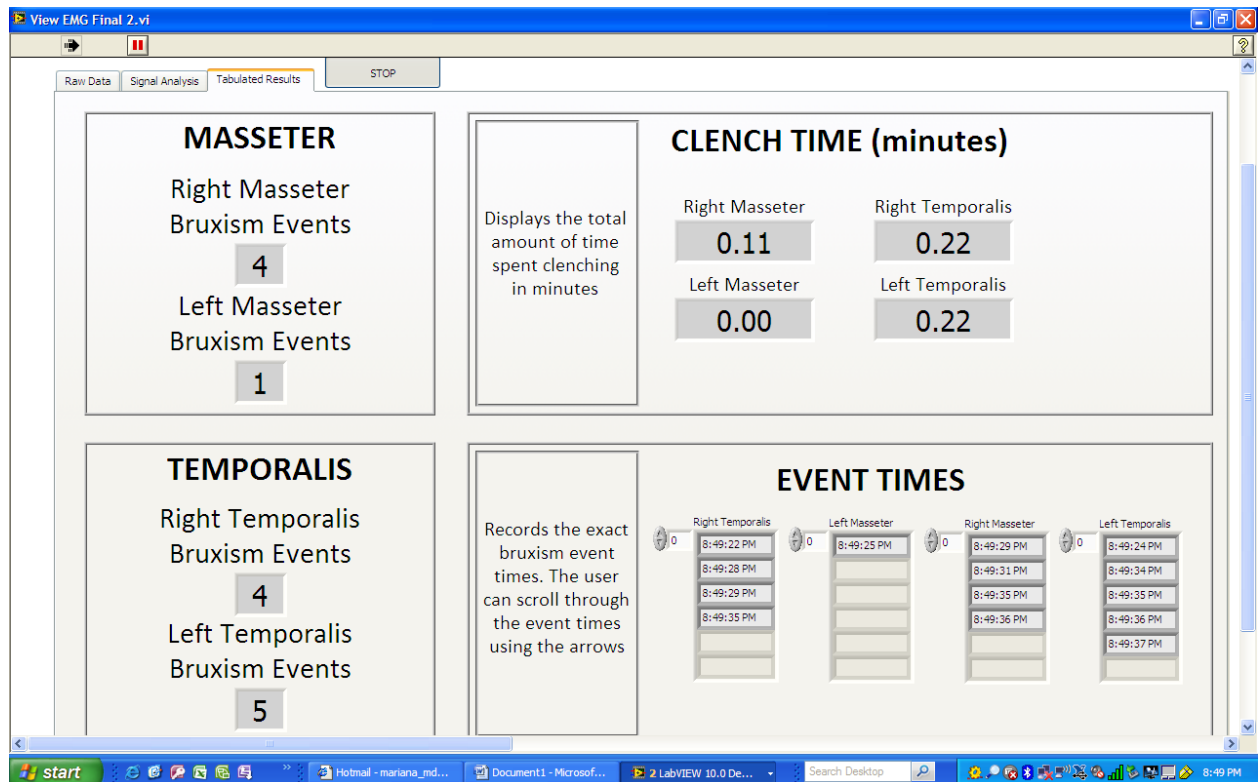


Figure 44. Signal Analysis tab of the TMJD Results Application showing rectified EMG signals of the four muscles.

The patient will return the TMJD Diagnostics device to the clinician, who will be able to view the results by running the TMJD Results Application. This application is also very user-friendly. At the start of this program, the clinician will see the screen shown in Figure 45. The clinician will be able to select the files to view by clicking on

the path controls, as indicated in Figure 45.

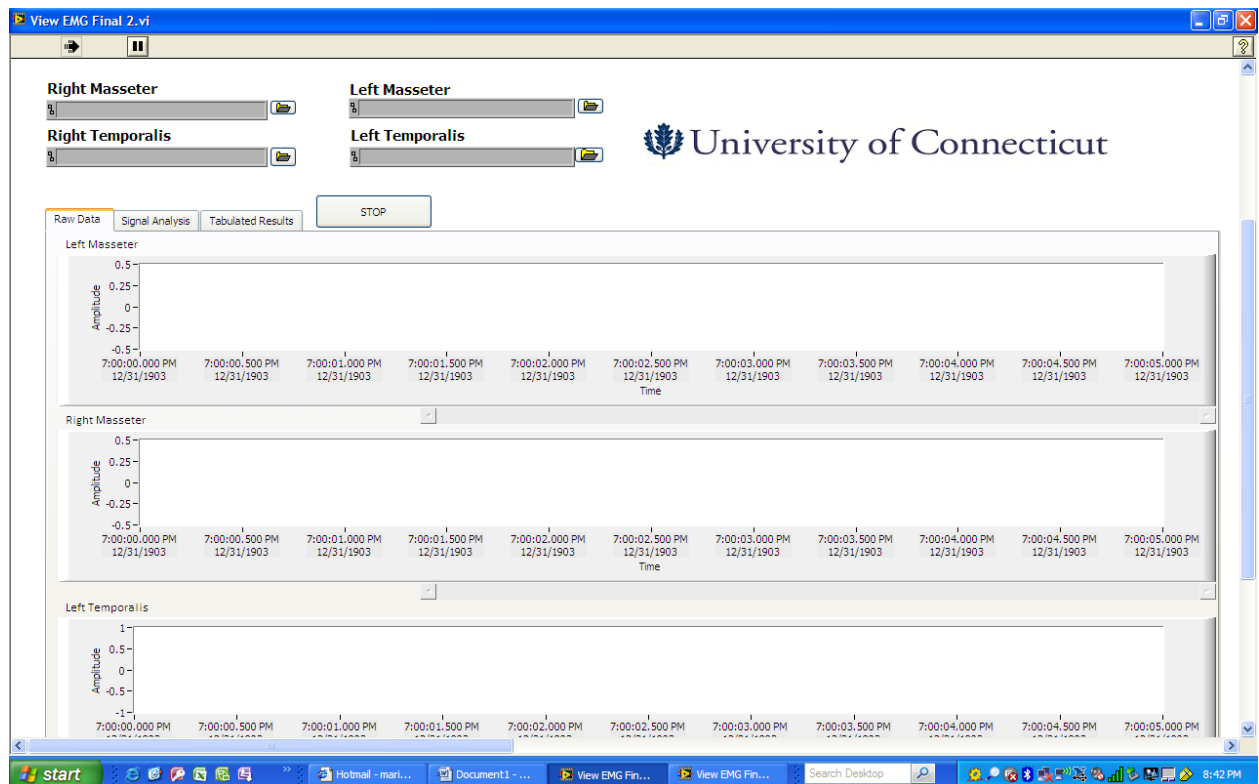


Figure 45. TMJD Results Application showing path controls, displays for the four muscles and the tabs for selecting Raw Data, Signal Analysis or Tabulated results.

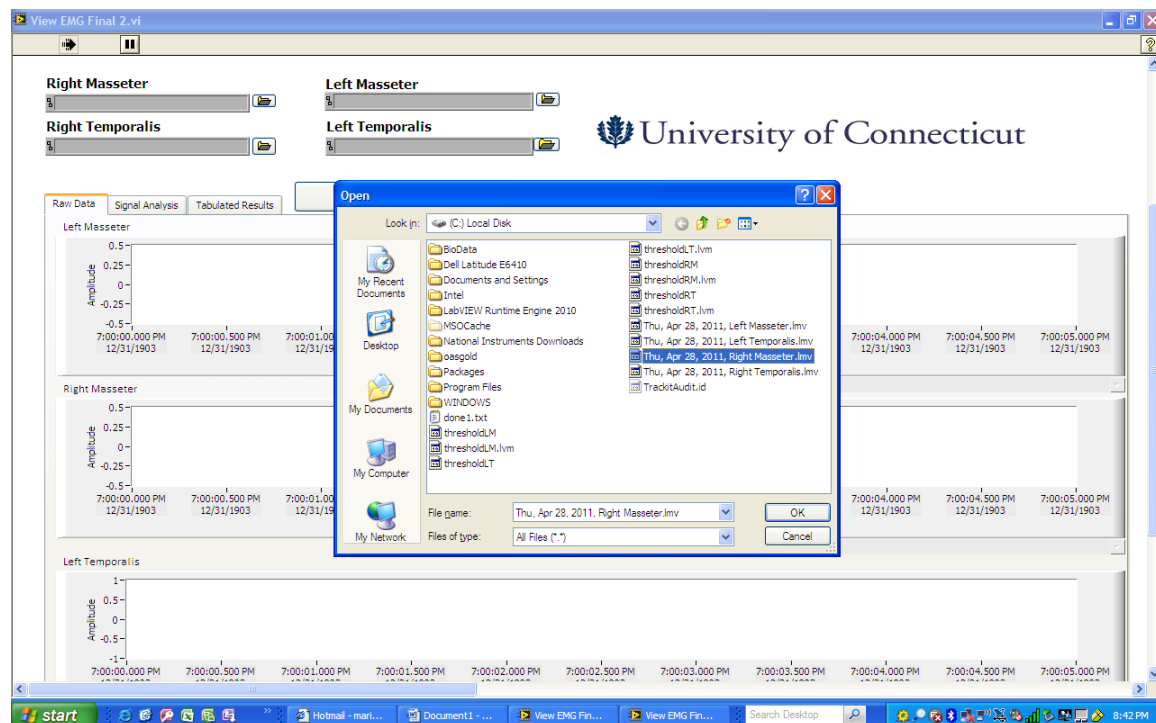


Figure 46. TMJD Results Application showing dialog box to select file to read.

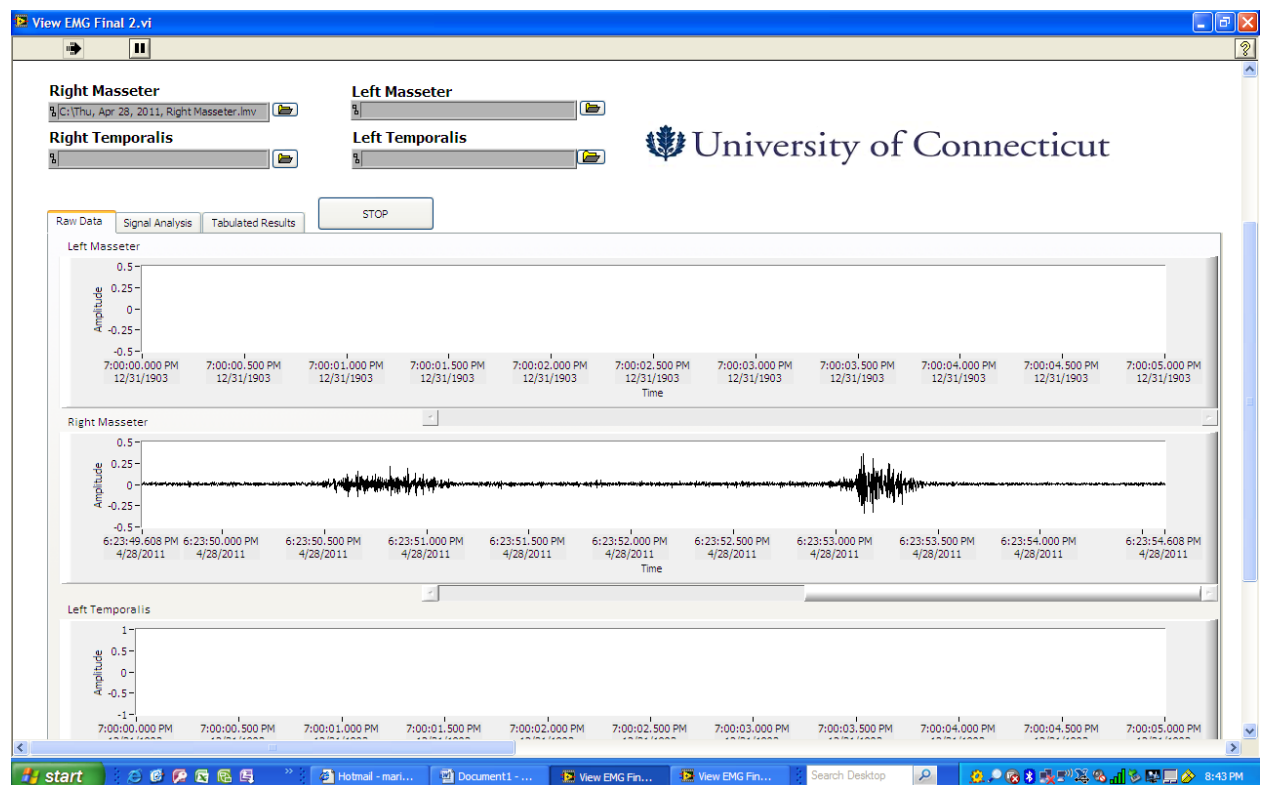


Figure 47. TMJD Results Application reading EMG file selected.

The raw EMG signals are displayed under the Raw signals tab; the rectified and rms EMG signals can be viewed under the Signal Analysis tab and the tabulated results are shown under the Tabulated results tab. All of these features make this application significantly helpful for the clinician to diagnose TMJD.

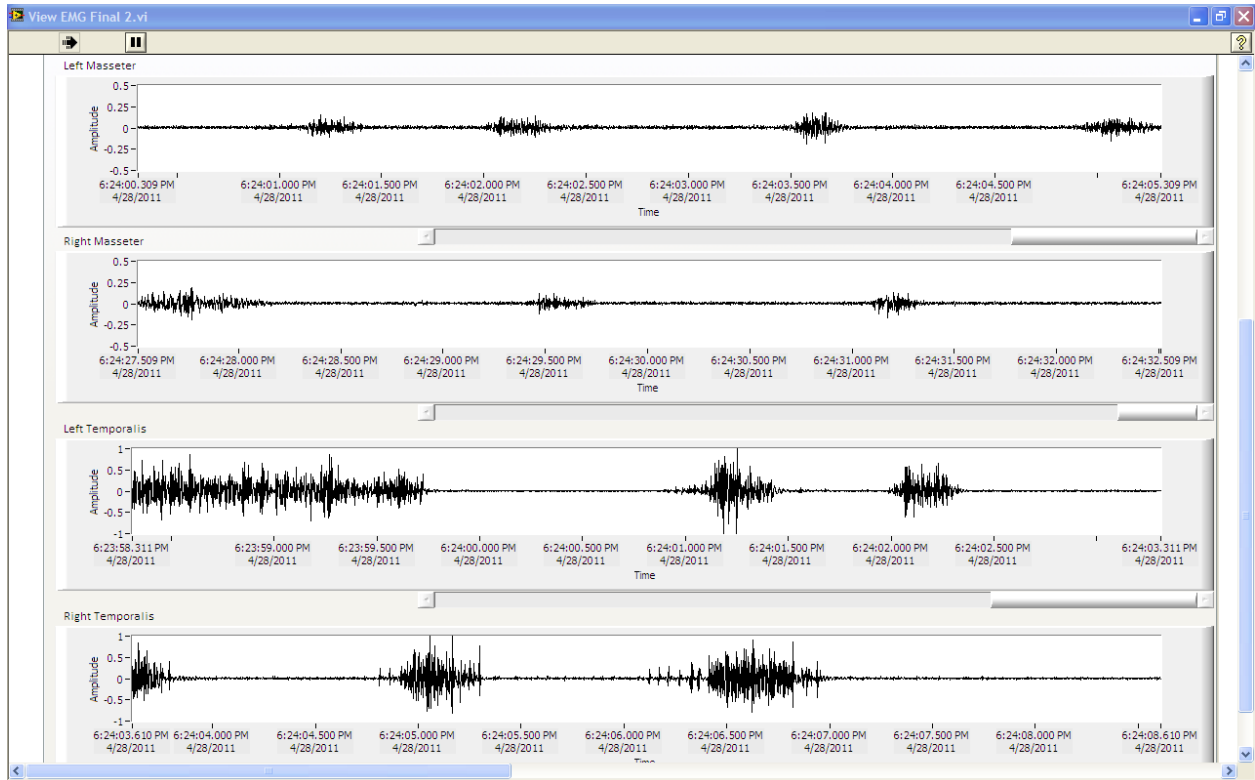


Figure 48. TMJD Results Application reading EMG files from the four muscles.

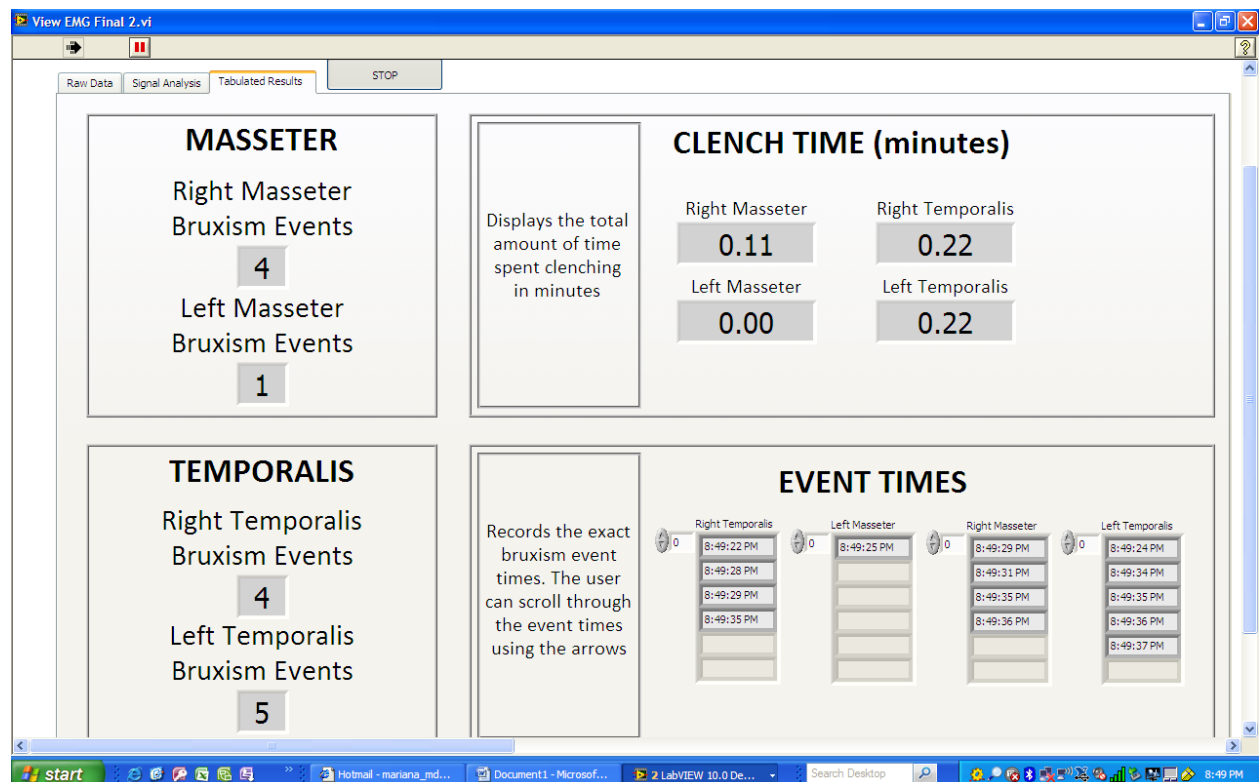


Figure 49. Signal Analysis tab of the TMJD Results Application showing rectified EMG signals of the four muscles.

3. REALISTIC CONSTRAINTS

There are a number of constraints related to our design of the device that are worth mentioning.

Many studies have found that bruxism is highly associated with Obstructive Sleep Apnea. Patients who are under treatment of this sleep disorder wear a Continuous Positive Air Pressure (CPAP) device, which is a mask-like machine that provides a constant stream of air, which keeps the patient breathing passages open while they sleep. An illustration of a standard CPAP device is shown in Fig. 50.



Figure 50. Standard CPAP device

Due to the fact that patients who suffer from Obstructive Sleep Apnea are likely to brux, when constructing the design of our wearable hat we took into consideration that it could not interfere with the CPAP device. Ideally, the patient suffering from Obstructive Sleep Apnea should be able to wear both the CPAP device and the bruxism diagnostics device as comfortably as possible.

Another observation is that most of the temporalis muscle is covered by hair. If the electrode were to be placed on hair, the signal may be significantly distorted due to the high input impedance from the electrode-skin interface. Therefore, it is important to correctly place the electrode to ensure optimal acquisition of the signal.

Another constraint has to do with the size of the hat. Because patients' head shapes and sizes vary, we designed a device that is fully adjustable for all head sizes. This is accomplished using a Velcro hook and loop fastener system

Finally, the use of the device requires handling a large amount of data throughout a long period of time without technical supervision. Hard disk memory is also limited. Therefore, the LabVIEW program that will continuously receive the EMG data, analyze it, and store it might experience unexpected errors while operating during the night. This would imply that the whole set of data would be lost. In order to avoid this, we maximized the efficiency of data transfer and storage by writing to a LabVIEW measurement file.

4. SAFETY ISSUES

This project is relatively safe and does not pose significant harm to any of the users. However, great care must go into considering all aspects of safety so that nothing is overlooked.

The patient using the device will be in an unconscious period of sleep when in use. Thus, they will not have the cognitive capacity to react quickly to a safety hazard. One safety concern is that of electrical shock. The patient will have numerous electrodes attached to their skin that may exhibit hazardous voltage potentials. Fig. 51 depicts the levels of electrical current corresponding to physiological response.

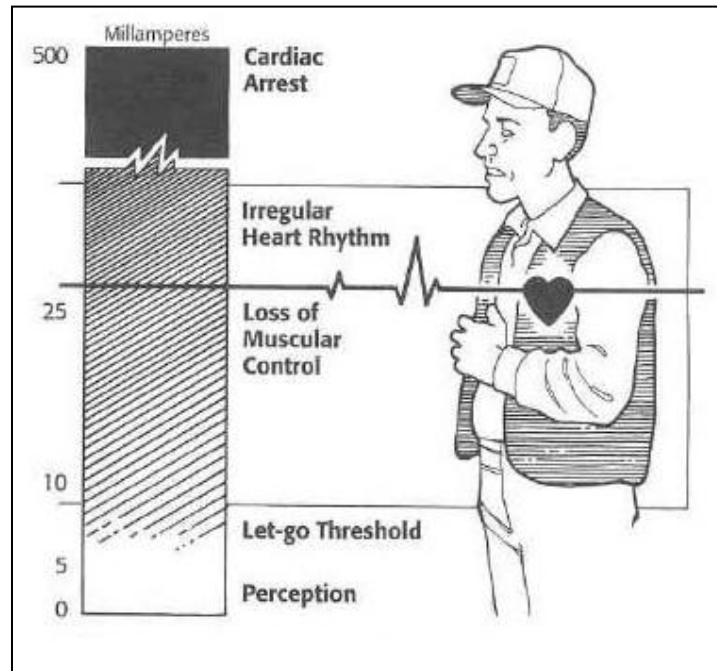


Figure 51. *Electrical shock to patient (Courtesy of National AG Safety Database)*

Electrical current in the hundreds of milliampere range may result in cardiac arrhythmias that degenerate into ventricular fibrillation and ultimately death. It is crucial that the patient is protected against any possibility of an electrical shock. A parallel diode configuration has been implemented into the design as shown in Fig. 9 to limit the voltage in contact with the user to 700 mV. The electrode potentials will likely never reach anywhere near this level, however, it is of vital importance to protect the patient regardless. Additionally, the wall transformer isolates the patient to ensure that there is no galvanic connection between the patient and the wall. The only possible current that could pass through to the patient is DC, which is not nearly as hazardous as AC current. The possibility of this event occurring is nearly impossible, however in the event of electric shock, the user should disconnect the power cable from the circuit enclosure immediately.

There may be a biological hazard as a result of the electrode-skin interaction. Some patients may be allergic to Ag-AgCl (silver-silver chloride) electrodes and may potentially have adverse reactions. A life-threatening anaphylaxis is unlikely; however, skin irritation may persist on the areas where the electrodes are connected. The Kendall / Tyco ARBO disposable electrodes are latex free and throughout extensive testing did not cause any adverse reactions.

Clinical trials should be conducted prior to release into the market. An Institutional Review Board (IRB) was been drafted by our client, Dr. Mark Litt, Ph.D., and is currently in the process of approval. During clinical trials, it is of utmost importance to ensure the safety of the volunteers. One member of the group (Mike) has been certified by the Collaborative Institutional Training Initiative (CITI) to perform clinical trials at the Storrs campus. Dr. Litt can likewise conduct trials at the UConn Health Center.

Another safety issue is that of sanitation between uses. The final product is machine washable, and the circuitry and electrode/electrode lead components are easily removable. The device is capable of being disassembled and reassembled by users who have been informally trained. The hat design of the project accommodates for this safety issue.

5. IMPACT OF ENGINEERING SOLUTIONS

If the proposed device were to be successful and widely accepted by the dentistry community, it may change the industry. First, the device would be more convenient and economical for the patient than staying overnight in a sleep lab (Fig. 52). The patient would no longer be required to sleep outside of the comforts of his or her home for the diagnosis of TMJD. This device will be much cheaper for insurance companies than the traditional sleep labs since there is no staff required to observe the patient and assure that the test is going well. This would also make the device less expensive for the patient.

Secondly, since sleep labs would no longer be needed for the diagnosis of TMJD, some may close due to a decreased demand, and some technicians may be out of work.

There is no similar device to this one on the market, so if successful, this product may be the only one like it and would initially have a monopoly on the market share. This would not last very long, as it would create competition within the industry.



Figure 52. *Patient wired in a sleep lab*

The proposed device is desirable for patients as well as clinicians. TMJD goes undiagnosed in many sufferers due to the inconvenience of going through testing in a sleep lab. The TMJD diagnostic device will take less time out of the patient's day than a trip to the sleep lab would. This could ultimately result in more activity for specialists in the sleep disorders field, and comfort from treatment for those who suffer from TMJD.

6. LIFE-LONG LEARNING

In order to carry out the project, new knowledge was acquired through intensive research of material. To begin with, we learned about the bruxism sleep disorder characteristics and symptoms. Moreover, we explored the current diagnosis methods for bruxism and their drawbacks. Based on these, we searched for new materials and methods with the aim to provide a better solution for the diagnosis of this sleep disorder. For example, we proposed non-adhesive electrodes that will improve the comfort of the individuals when placing them in the different locations on the face and the use of wireless technology to allow more freedom of movement for the patient during sleep.

We also gained experience working as a team, having to exchange opinions and debating different ideas, as well as having to meet strict deadlines. Moreover, we experienced the relationship with a client and the fact of dealing with a limited budget to carry out the project. This implies that every specification of our design should meet the needs of our client in order to ensure the satisfaction of the final product, at the same time that we carefully select our design in order to stay within our budget.

In our design we included the EMG circuit and a LabVIEW program to process the data. Although we were familiar with both tools throughout academic courses, this time we are applying them to solve a real need. By collecting EMG signals from individuals who suffer from bruxism, we learned the patterns that characterize clenching and grinding of the teeth that allow for the diagnosis of the disorder.

7. BUDGET

7.1 Budget

The total prototyping costs came to a total of \$2,451.07. The total cost per device would be \$1836.02. The cost of each device is outlined in Table 53. We were allotted a total budget of \$6,000, were under budget by over \$3,000.

<i>Component</i>	<i>Cost</i>
<i>Electrodes</i>	<i>\$36.33</i>
<i>Electrode leads</i>	<i>\$192.45</i>
<i>Circuit</i>	<i>\$117.51</i>
<i>PCB</i>	<i>\$40.73</i>
<i>Neuroband Components</i>	<i>\$80.00</i>
<i>DAQ</i>	<i>\$169.00</i>
<i>Laptop</i>	<i>\$1,200.00</i>
<i>TOTAL</i>	<i>\$1836.02</i>

Table 53. Budget for final design

The circuit components (for each device) are broken down in Table 53.

Part	Value	Price Each	Quantity	Ext. Price	Usage Description
R1, R2, R3, R7, R8, R9, R13, R14, R15, R19, R20, R21	100 k Ω	\$ -	12	\$ -	Impedance resistors to electrodes
D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16	FDH333 Diode	\$ 0.32	16	\$ 5.18	Patient protection circuitry
R4, R10, R16, R22	150 Ω	\$ -	4	\$ -	Gain resistors for instrumentation amplifier
C13, C14, C15, C16, C17	1 μ F (electrolytic)	\$ -	5	\$ -	Power bypass coupling capacitors
R5, R11, R17, R23	82 k Ω	\$ -	4	\$ -	Bandpass filter
R6, R12, R18, R24	330 k Ω	\$ -	4	\$ -	Bandpass filter
C1, C4, C7, C10	0.1 μ F	\$ -	4	\$ -	Bandpass filter
C2, C5, C8, C11	1 nF	\$ -	4	\$ -	Bandpass filter
C3, C6, C9, C12	0.1 μ F	\$ -	4	\$ -	Coupling capacitors

LED	Green LED	\$	0.11	1	\$	0.11	Power indication LED
R_LED	220 Ω	\$	-	1	\$	-	Current-limiting resistor to LED
U1, U2, U3, U4	AD620	\$	7.06	4	\$	28.24	Instrumentation Amplifier
U5	TL074	\$	0.65	1	\$	0.65	Bandpass filter op amp
ADDITIONAL COMPONENTS:							
Part	Value		Price Each	Quantity		Ext. Price	Usage Description
IC DIP socket 8 pin	-	\$	0.94	4	\$	3.76	Socket for AD620s
IC DIP socket 14 pin	-	\$	1.63	1	\$	1.63	Socket for TL074
Rocker DPST switch	-	\$	6.26	1	\$	6.26	Power switch
DIN Female	-	\$	1.63	1	\$	1.63	DC input
Transformer	-	\$	86.58	1	\$	86.58	Wall transformer
Enclosure	-	\$	7.20	1	\$	7.20	Circuit Enclosure
PCB	-	\$	40.73	1	\$	40.73	Printed Circuit Board
TOTAL						\$ 181.97	

Table 54. Budget breakdown for circuit components

8. TEAM MEMBERS CONTRIBUTION TO THE PROJECT

8.1 Michael Jorgensen

My contribution to the project included research on electromyography, research on biopotential amplifiers for EMG, website construction/maintenance, electrode/electrode lead purchasing, touch-proof connection design, circuit design, circuit construction, microcontroller programming, LabVIEW programming, Bluetooth interface, protoboard testing, PCB design and testing, enclosure construction, and final product testing.

As part of my research I read numerous articles relating to electromyographic studies of temporomandibular joint disorder, particularly those with reference to circuit electronics. I referenced several books from the library, including John Webster's *Medical Instrumentation* and Jeffrey Cram's *Introduction to*

Surface Electromyography, which I used as a reference for much of the circuit design and electrode placement methods. I shared the information obtained from my research with the team members to inform them of the current methods for electromyography.

I created the group website early and maintained it throughout both semesters. This account included all updates, document uploads, and general maintenance issues. The email allowed us to communicate effectively and have access to all important documents, as well as providing Dr. Litt with a means to view the information as well.

I contacted several companies regarding sample reusable electrodes so that our group could test them before committing to purchase them. Of the companies I contacted, In Vivo Metric supplied us with a donation of one Ag-AgCl reusable electrode. I researched several disposable electrodes as well and confirmed that the Kendall / Tyco ARBO electrodes were the best option for this project.

I designed and constructed the electromyography circuit throughout both semesters. I learned the C programming language over winter break and in my microcontroller applications lab to effectively program the microcontroller in embedded C, however this was removed from the project due to time constraints. My theory behind circuit construction was to build one stage of the circuit at a time so that each could be tested separately and completely isolated from the other circuit stages. For final circuit testing protocol, the stages were connected and EMG signals were acquired from the temporalis and masseter muscles of a test subject.

I maintained the team website throughout both semesters by uploading all recent documents and ensuring that all information was current.

I contacted multiple companies for the electrode leads, and had difficulty in finding male 1.5 mm touch proof connectors to interface with the snap electrode leads. Ultimately I discovered Bioconnect, who provided us with some free samples as well as the cables that are utilized in the final product.

A Bluetooth wireless interface was attempted but was eliminated from the final product strictly for time constraint reasons. For future applications, adding Bluetooth capability will be a major improvement over a wired connection. The circuit was designed to operate from ± 9 V, so portability is possible and the PCB would not have to be significantly altered.

I designed, ordered, populated, and tested the PCB. The design stage took about a week because I checked connections multiple times to ensure that another PCB would not have to be ordered. Fortunately, the PCB worked right from the power up, and never presented any problems. I can confidently say that the design is solid and all future improvements should keep a relatively similar design.

I designed, ordered, and assembled the enclosure. In terms of durability, the enclosure should provide a good level of protection to the circuit and internal components. It is advisable that the user should not drop the device or expose the device to liquids or flammable materials. Some improvements to the enclosure may include aluminum or steel casing, however these were avoided due to the ease of manufacturing with a plastic enclosure.

I designed and programmed the LabVIEW program to acquire the EMG signals as well as write the data to a LabVIEW measurement file. My program interfaced with Mariana's program so that the data could be read in by a second VI.

Additionally, I took a major role in final product testing. With real-time EMG data acquisition, I was able to alter the LabVIEW code accordingly to present the user with the most accurate results and intuitive graphical user interface.

Overall, I was very satisfied by the progress of the project and the cooperation and effort by my team members. It is rewarding to witness the final product and it is my hope that this device will continued to be manufactured and used to help temporomandibular joint disorder patients in the United States and around the world.

8.2 Kerry Semle

Kerry's contributions to the project were primarily organizational and aid-related. Kerry organized and saved all literature used on the project to a Google Documents account.

The Google Documents account gave the team a place to save documents so that they could all access them. These documents included reports, presentations, literature, the project timeline, the total budget spreadsheet, and individual purchase orders.

Kerry managed the Microsoft Project Timeline and kept the other team members up to date and organized expected completion dates for tasks in the project. She also kept a running total budget for the team, and separated items purchased using the Biomedical Engineering funds from items purchased by the UConn Health Center.

Kerry also established protocol for testing different electrode types for use in the final project and brainstormed several different electrode housing designs for the team to decide upon. Kerry integrated the electrode snap leads into the Neuroband and sewed the device together.

Before the team decided that they were going to use a serial connection instead of a Bluetooth connection for sending data to the computer, Kerry had designed and drew in SolidWorks a custom enclosure for housing the Bluetooth and circuitry.

8.3 Mariana Hu

My contribution to the project includes design and implementation of the LabVIEW program in charge of data acquisition, storage and analysis, learning to use the LabVIEW VISA functions, doing research on methods to interface Bluetooth with the microprocessor, doing research on different types of electrodes and helping with parts ordering.

For the data acquisition stage, we were provided the code used for the completion of the Vital Signs Monitoring Project. This code read the data sent to the computer via Bluetooth as a serial port and used the LabVIEW VISA functions. It was modified in order to adapt to our application. However, due to a change in our project design, this code was not used.

I also did research regarding Bluetooth interfacing, but due to a time constraint this design was not used.

I have also contributed to the selection of the disposable electrodes that have integrated gel and features a snap-on connector that can easily be pushed on or removed from the electrode lead.

I created a front panel design that is very user-friendly and includes different tabs for the specific functions of the program. There is one tab per muscle, one tab that allows the clinician to set the thresholds and another tab for the patient's view. The muscles' tabs include the views of the EMG, of the rectified EMG and the RMS EMG. There is also a path control for selecting the file to view. A push button initiates and stops the display of signals. The tab for threshold selection allows the clinician to select a threshold for each muscle for signal recording. A Save button saves the value into a file. The tab for the patient's view includes a Start/Stop button and a green LED that indicates that data acquisition has begun. On the left side of the front panel, there is a slider control to adjust the velocity at which signals are displayed.

I also carried out research on existing products and concluded that our design would offer advantageous features compared to them. Our design features a unique Neuroband Data Acquisition Unit and provides the clinician with useful information for TMJD diagnosis. Not only it provides the raw EMG data but also the rectified and RMS signals.

Finally, in order to make our design safer for the patient, I proposed the use of a coiled cable to connect the laptop to the circuit enclosure. This way, the movement of the patient will not pull the laptop away so easily.

9. CONCLUSION

The TMJD Diagnostics device improves the screening and diagnosis of TMJD by providing benefits to both the clinician and the patient. The device proved to acquire accurate data while allowing the patient to be screened comfortably at home. It also presents advantageous features such as user-friendliness, portability and the possibility of repeated usage since it is washable.

The fact that this device maintains the accuracy and efficacy of sleep studies while providing the patient with the comfort to be screened in their home environment make it extremely beneficial for the patient and the patient. The clinician does not need to instruct the patient in the usage of the device since simple instructions are provided to the patient at the beginning of the TMJD Diagnostics application. The interface is very user-friendly and additional help is provided if needed. The patient will be screened in the natural sleeping habits since he will not be required to stay overnight in a sleep lab, which is often uncomfortable and expensive.

In addition, the design of the Neuroband is unique in that it secures the electrodes in place efficiently and allows for repeated usage since it can be washed.

The TMJD Diagnostics device also provides the clinician with valuable diagnostic information. Not only the raw EMG signals are displayed, but also the rectified and rms EMG signals. Moreover, data is processed to provide tabulated results showing total number of bruxing events per muscle, the total duration of the events and the exact times of occurrence of these events. Current devices do not offer these features, which are helpful for an accurate diagnosis of TMJD.

Finally, the light weight and portability of the system make it optimal for home use.

All of these features are vast improvements on the current techniques for temporomandibular joint disorder diagnosis.

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11. ACKNOWLEDGEMENTS

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Marek Wartenberg
Sonia Helena Contreras Ortiz
Dave Kaputa
Antonio Costa
Penny Dobbins
Kerrie Wenzler
Jennifer Desrosiers

These individuals were instrumental in the development of the TMJD Diagnostics System.

12. APPENDIX

12.1 Updated Specifications

The circuitry underwent several revisions throughout both semesters and will be described herein.

Initially, RC lowpass and highpass filters were implemented into the design to provide a first-order filtering of the non-amplified EMG signals. These were removed per request of Dr. John Enderle due to the fact that they would filter out frequencies in the bandwidth. This was tested on the protoboard and they did not provide sufficient filtering characteristics. Thus, they were been removed from the final design.

Secondly, the 60 Hz notch filter was initially designed to remove 60 Hz frequencies utilizing a Twin T filter with a high Q factor. The filter was tested with physical components and the results were that of severe distortion of the EMG signal. Due to the fact that the device will not be used in an environment of high electromagnetic interference, it was removed from the final product design.

A Bluetooth connection was described as the optimal design for this project and it still stands to offer many benefits over the final product. This was removed from the project due to time constraints with microcontroller programming, data encryption, auto-play script, and other factors with Bluetooth protocol.

Initially, reusable electrodes were considered to be optimal for this project due to their repeated usage capability. They did provide signal quality similar to the disposable adhesive surface electrodes; however, they were removed from the final product design due to their inability to maintain solid connection to the skin for extended periods of time. They also presented problems with sanitation, as they were difficult to sanitize with conventional methods, and might pose health risks as the device is transferred to other patients.

12.2 Microcontroller Code in Embedded C

```
/******  
University of Connecticut Biomedical Engineering  
BME 4910 Senior Design  
Temporomandibular Joint Disorder Diagnostics Device  
Michael Jorgensen  
Kerry Semle  
Mariana Hu  
This code is free to be used by anyone without the consent of the authors.  
*****/  
  
#define F_CPU 1000000UL  
#include <avr/io.h>  
#include <avr/interrupt.h>  
#include <util/delay.h>  
  
// Global variables for battery level indicator function  
unsigned int max_value=0;
```



```

unsigned int Vin=0;
unsigned int decimal;
unsigned int data;
unsigned int wholeVin;
unsigned int tenth_decimal;

// Global variables for signal multiplexing
unsigned char sig1;
unsigned char sig2;
unsigned char sig3;
unsigned char sig4;
unsigned int Vin1=0;
unsigned int Vin2=0;
unsigned int Vin3=0;
unsigned int Vin4=0;
unsigned int MuxOut;

//Initialize analog-to-digital converter
void InitADC(void)
{
    ADMUX = 0; //Select channel 0
    ADCSRA = 0xC3;
    //Enable ADC & start 1st dummy conversion
    //Set ADC module prescaler to 8
    //critical for accurate ADC results
    while (!(ADCSRA & 0x10)); //Check if conversation is ready
    ADCSRA |= 0x10;
    //Clear conv rdy flag - set the bit
}

unsigned int ReadADC(unsigned char channel)
{
    unsigned int binary_weighted_voltage, binary_weighted_voltage_low;
    unsigned int binary_weighted_voltage_high; //weighted binary
voltage
    ADMUX = channel; //Select channel
    ADCSRA |= 0x43; //Start conversion
    //Set ADC module prescaler to 8
    //critical for accurate ADC results
    while (!(ADCSRA & 0x10)); //Check if conversion is ready
    ADCSRA |= 0x10; //Clear Conv rdy flag - set the bit
    binary_weighted_voltage_low = ADCL; //Read 8 low bits first
(important)
    //Read 2 high bits, multiply by 256
    binary_weighted_voltage_high = ((unsigned int)(ADCH << 8));
    binary_weighted_voltage = binary_weighted_voltage_low
    | binary_weighted_voltage_high;
    return binary_weighted_voltage; //ADCH:ADCL
}

void PWM0B_init(void)
{
    DDRB |= (1 << PORTB4); //set output channel - PWM0B
    TCCR0A |= (1 << COM0B1); //no-inverting mode
    TCCR0B |= (1 << WGM02);
    TCCR0A |= (1 << WGM01) | (1 << WGM00); //fast pwm mode 7
    TCCR0B |= (1 << CS01); //clk/8
    OCR0A = 62.5; //set frequency at 16kHz with clk=8MHz and CS=1
}

```

```

        OCR0B = ((ADCH +1)*(OCR0A+1)) / 128 - 1; //set the duty cycle
        TIMSK0 |= (1 << OCIE0B) | (1 << TOIE0); //enable COMPB and OVF interruptions
    }

    /*******
    Battery level indicator designed for use with a bi-color LED (Green, Red)
    *****/
    void BatteryLevelIndicator(void)
    {
        DDRD = 0xFE;

        data = ReadADC(0);
        Vin = 100*((data*5.001)/1023);

        decimal=Vin%100;

        wholeVin = (Vin/100)+0x30; // Whole number voltage
        tenth_decimal = ((decimal/10)+0x30); // Tenths place decimal

        if(wholeVin >= 0x35) // Greater than or equal to 5.0 V = Green
        {
            PORTD=0xFB;
        }
        if(wholeVin >= 0x34 && wholeVin != 0x35)
        {
            if(tenth_decimal >=0x39) // Greater than or equal to 4.9 V
= GREEN
            {
                PORTD=0xFB;
            }
            if(tenth_decimal <0x39 && tenth_decimal >=0x35) // Range
4.5 V - 4.9 V = YELLOW
            {
                PORTD=0xFF;
            }
            if(tenth_decimal <0x35) // Less than 4.5 V = RED
            {
                PORTD=0xF7;
            }
        }
        if(wholeVin <0x34)
        {
            PORTD=0xF7;
        }
    }

    /*******
    Signal Multiplexing - time division MUX of four inputs into one output
    *****/
    void SignalMultiplexer(void)
    {
        // PORT directions
        DDRD = 0xFE;
        DDRA |= 0xE0;

        // Read in signals
        sig1 = ReadADC(1);
        // sig2 = ReadADC(2);

```



```

void InitLCD(void);
void DisplayC(unsigned char position, const char *str);
void DisplayCharacter(unsigned char pos, unsigned char c);
void clear_display(void);
void InitSerial(void);
void SerialString(const char *str);
void SerialCharacter(unsigned char c);
char SerialReception(void);
int Speed;

//;;;;;;;;; Initial subroutine ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
//; This subroutine performs all initializations of variables and registers.

void Initial(void)
{
    ADCS0 = 1;                // Use A/D FOSC/8
    ADCON1 = 0x44;            // Select PORTA pins for ADC or digital I/O
    TRISA = 0x0B;             // Set I/O for PORTA
    TRISB = 0xE1;             // Set I/O for PORTB
    TRISC = 0xB7;             // Set I/O for PORTC
    TRISD = 0x00;             // Set I/O for PORTD
    TRISE = 0x04;             // Set I/O for PORTE
    PORTD = 0;                // Turn off LEDs
    // OPTION = 0b00000100; // Timer 0 prescale set 32:1
    // INTCON = 0b11100000; // Enable Timer 0 interrupts
    InitLCD();
    InitSerial();
}

void ADConvert(void)
{
    CHS0 = 1;                 // Use channel AN1
    ADON = 1;                 // Turn A/D on
    __delay_us(30);           // delay 30 usec to settle A/D acquisition
    ADGO = 1;                 // Start conversion
    while ( ADGO );           // wait for ADGO to go off signalling end of
conversion
    Speed = ADRESH;
}

//;;;;;;;;; Mainline program ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

int main(void)
{
    char c;
    int i=0;

    Initial();
    DisplayC(0x80, "Lab 10");
    SerialString("UCONN Huskies");

    for(;;)
    {
        c=SerialReception();
        if (i==16)
        {
            i=0;
            clear_display();

```

```

        DisplayC(0x80, "Lab 10");
    }
    DisplayCharacter(0xC0+i,c);
    i++;
}
}

```

12.4 Bluetooth Serial Connection Code in Embedded C

```

#include <htc.h>

void InitSerial(void)
{
    TXSTA = 0b00100100; // Enable TXEN and BRGH
    RCSTA = 0b10011000; // Enable SPEN and CREN
    SPBRG = 47;          // 9600 Baud for 7.37MHz
    TRISC7 = 1;          // Set C7 (RX) as input
    TRISC6 = 0;          // Set C6 (TX) as output
    RP0 = 0;             // Force bank 0
}

void SerialString(const char *str)
{
    for ( ; *str; str++ )
    {
        while(!TXIF)      /* set when register is empty */
            continue;
        TXREG = *str;
    }
}

void SerialCharacter(unsigned char c)
{
    while(!TXIF)          /* set when register is empty */
        continue;
    TXREG = c;
}

char SerialReception(void)
{
    while(!RCIF)          /* set when register is not empty */
        continue;
    return RCREG;
}

```

12.5 Data Sheets

Due to the size of the datasheets for the AD620 and TL074, they have been shortened to show critical information including important parameters and applications information. The AD620 instrumentation amplifier datasheet is shown below.



Low Cost, Low Power Instrumentation Amplifier

AD620

FEATURES

EASY TO USE

Gain Set with One External Resistor
(Gain Range 1 to 1000)

Wide Power Supply Range (± 2.3 V to ± 18 V)
Higher Performance than Three Op Amp IA Designs
Available in 8-Lead DIP and SOIC Packaging
Low Power, 1.3 mA max Supply Current

EXCELLENT DC PERFORMANCE ("B GRADE")

50 μ V max, Input Offset Voltage
0.6 μ V/ $^{\circ}$ C max, Input Offset Drift
1.0 nA max, Input Bias Current
100 dB min Common-Mode Rejection Ratio ($G = 10$)

LOW NOISE

9 nV/ $\sqrt{\text{Hz}}$, @ 1 kHz, Input Voltage Noise
0.28 μ V p-p Noise (0.1 Hz to 10 Hz)

EXCELLENT AC SPECIFICATIONS

120 kHz Bandwidth ($G = 100$)
15 μ s Settling Time to 0.01%

APPLICATIONS

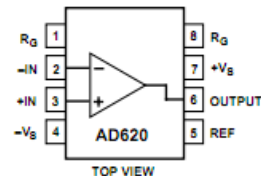
Weigh Scales
ECG and Medical Instrumentation
Transducer Interface
Data Acquisition Systems
Industrial Process Controls
Battery Powered and Portable Equipment

PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to

CONNECTION DIAGRAM

8-Lead Plastic Mini-DIP (N), Cerdip (Q)
and SOIC (R) Packages



1000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs, and offers lower power (only 1.3 mA max supply current), making it a good fit for battery powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 μ V max and offset drift of 0.6 μ V/ $^{\circ}$ C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Superbeta processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/ $\sqrt{\text{Hz}}$ at 1 kHz, 0.28 μ V p-p in the 0.1 Hz to 10 Hz band, 0.1 pA/ $\sqrt{\text{Hz}}$ input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 μ s to 0.01% and its cost is low enough to enable designs with one in-amp per channel.

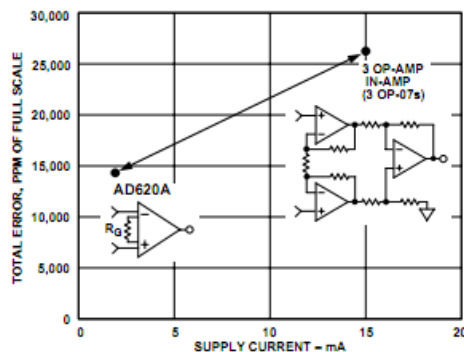


Figure 1. Three Op Amp IA Designs vs. AD620

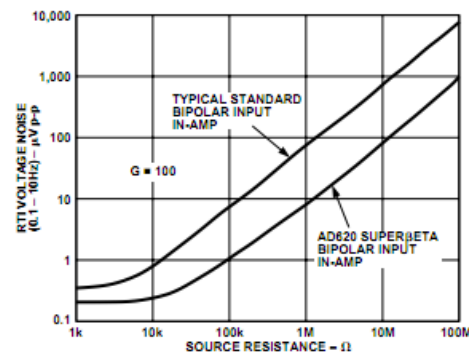


Figure 2. Total Voltage Noise vs. Source Resistance

REV. E

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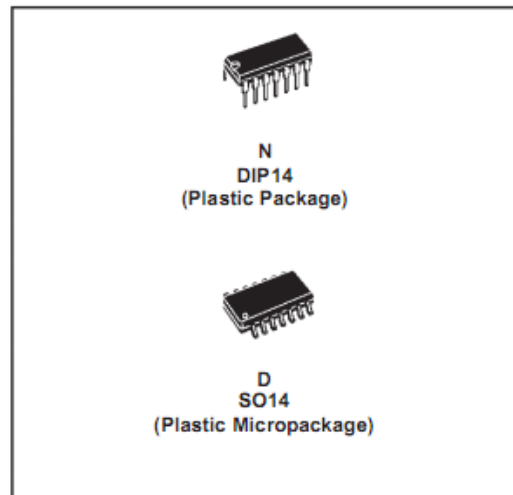
The TL074 low noise JFET quad operational amplifier is shown below.



TL074 TL074A - TL074B

LOW NOISE J-FET QUAD OPERATIONAL AMPLIFIERS

- WIDE COMMON-MODE (UP TO V_{CC}^+) AND DIFFERENTIAL VOLTAGE RANGE
- LOW INPUT BIAS AND OFFSET CURRENT
- LOW NOISE $e_n = 15\text{nV}/\sqrt{\text{Hz}}$ (typ)
- OUTPUT SHORT-CIRCUIT PROTECTION
- HIGH INPUT IMPEDANCE J-FET INPUT STAGE
- LOW HARMONIC DISTORTION : 0.01% (typ)
- INTERNAL FREQUENCY COMPENSATION
- LATCH UP FREE OPERATION
- HIGH SLEW RATE : $13\text{V}/\mu\text{s}$ (typ)



DESCRIPTION

The TL074, TL074A and TL074B are high speed J-FET input quad operational amplifiers incorporating well matched, high voltage J-FET and bipolar transistors in a monolithic integrated circuit.

The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient.

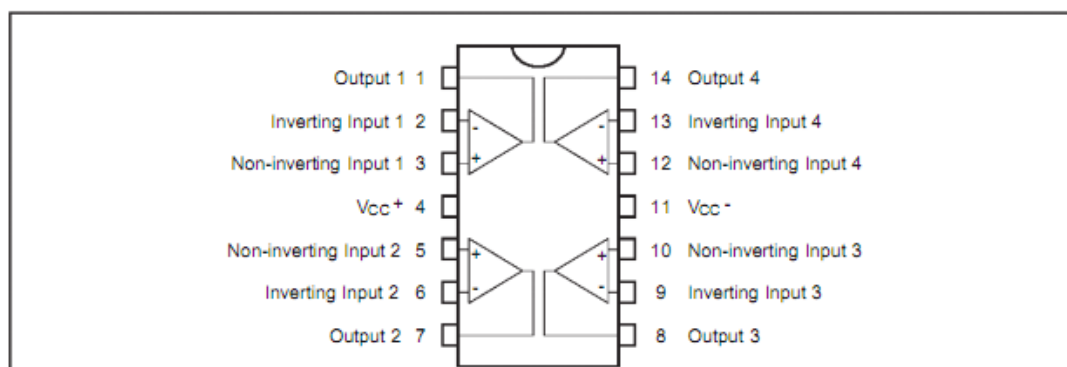
ORDER CODE

Part Number	Temperature Range	Package	
		N	D
TL074M/AM/BM	-55°C, +125°C	•	•
TL074I/AI/BI	-40°C, +105°C	•	•
TL074C/AC/BC	0°C, +70°C	•	•

Example : TL074IN

N = Dual In Line Package (DIP)
D = Small Outline Package (SO) - also available in Tape & Reel (DT)

PIN CONNECTIONS (top view)



March 2001

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National Instrument's USB 6008 OEM is shown below. The USB 6008 is a critical component of this project and therefore the entire datasheet is available for viewing. It may also be accessed at:

<http://www.ni.com/pdf/products/us/371728b.pdf>

USER GUIDE

NI USB-6008/6009 OEM

This document provides information about the dimensions, connectors, and other components of the National Instruments USB-6008/6009 OEM device. For more information about the device, refer to the *USB-6008/6009 User Guide and Specifications* document available at ni.com/manuals.



Caution There are no product safety, electromagnetic compatibility (EMC), or CE marking compliance claims made for the NI USB-6008/6009 OEM devices.

The NI USB-6008/6009 OEM device is intended to be used as a component of a larger system. National Instruments can help developers meet their compliance requirements. The end product supplier, however, is responsible for conforming to any and all compliance requirements.

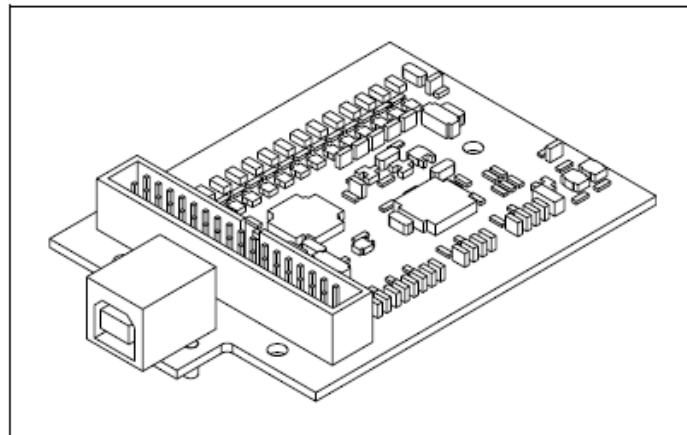


Figure 1. USB-6008/6009 OEM Device



ni.com

I/O Connector

Figure 3 shows the USB-6008/6009 OEM device I/O connector pinout. AI signal names are shown in single-ended mode. Differential mode signal names are in parentheses.

+5 V	34	33	PFI 0
D GND	32	31	P1.3
P1.2	30	29	P1.1
P1.0	28	27	P0.7
P0.6	26	25	P0.5
P0.4	24	23	P0.3
P0.2	22	21	P0.1
P0.0	20	19	D GND
LED	18	17	D+
VBUS	16	15	D-
AI GND	14	13	AI GND
AI 4 (AI 0-)	12	11	AI 0 (AI 0+)
AI 5 (AI 1-)	10	9	AI 1 (AI 1+)
AI 6 (AI 2-)	8	7	AI 2 (AI 2+)
AI 7 (AI 3-)	6	5	AI 3 (AI 3+)
AI GND	4	3	AI GND
AO 1	2	1	AO 0

Figure 3. USB-6008/6009 OEM Terminal Assignments

Signal Descriptions

Most of the signals available on the I/O connector are described in the *USB-6008/6009 User Guide and Specifications* document available for download at ni.com/manuals. Table 1 describes additional signals on the I/O connector of the OEM devices.



Note The +2.5 V signal is not available on the USB-6008/6009 OEM device.

Table 1. Signal Descriptions

Signal Name	Reference	Direction	Description
VBUS	GND	Input	USB Power
D+, D-	GND	Input/Output	USB Data Lines
LED	GND	Output	Status LED Driver

For more information about USB signals, refer to the *Universal Serial Bus Specification* accessible at www.usb.org.

Using the 34-Pin Connector with a Board Mount Socket

The USB-6008/6009 OEM device can be mounted to a motherboard using the 34-pin connector, as shown in Figure 4 and Figure 5.

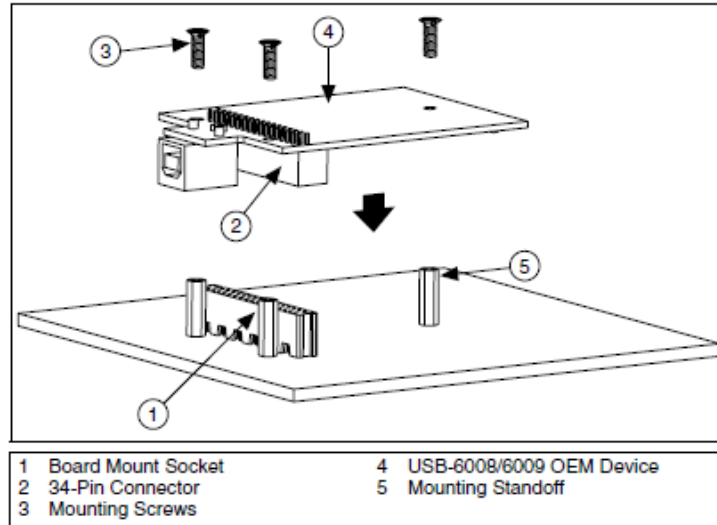


Figure 4. Mounting Using a 34-Pin Connector



Note Refer to the [Device Components](#) section for more information about mounting components.

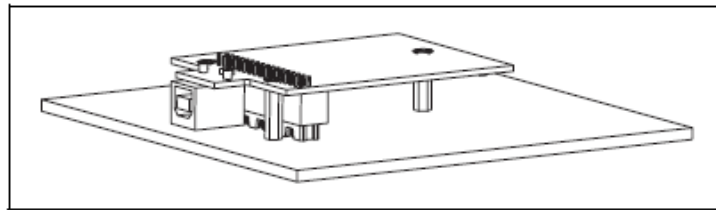


Figure 5. USB Device Installed on Motherboard

Connecting to USB

You can use the USB connector on the USB-6008/6009 OEM device to connect to the USB host. In this case, leave the D+ and D- signals (on the 34-pin connector) and VBUS unconnected. If +5 V is needed, supply it from the 34-pin connector.

You can also use a USB connector on your motherboard to connect the USB-6008/6009 OEM device to the USB host through the 34-pin connector. In this case, do not connect to the USB connector on the USB-6008/6009 OEM device.

Using the Status LED Driver

The LED signal indicates the device status as described in Table 2. An open collector driver drives the LED signal. For applications that use the LED signal, connect a 4.7 k Ω resistor from the LED signal to the +5 V signal.

Table 2. Device Status/LED Signal Behavior

Device Status	LED Signal Behavior
USB device enumerated, configured and not suspended	Square wave with frequency of 2 Hz
USB device is not enumerated, not configured, or is suspended	Not driven (pulled up)

Two possible uses of the LED signal are as follows:

- To drive an LED to give a visual indication that the device is active.
- To drive a watchdog timer circuit that monitors the device state.

Electrical Characteristics

Table 3 lists the LED electrical characteristics.

Table 3. Electrical Characteristics

Parameter	Conditions	Min	Typ	Max
LED Output Low Voltage	$I_{OL} = 8.5 \text{ mA}$	—	—	0.6 V
	$I_{OL} = 10 \text{ }\mu\text{A}$	—	—	0.1 V
	$I_{OL} = 25 \text{ mA}$	—	1.0 V	—

Device Components

Table 4 lists the components used for interfacing and interacting with the USB-6008/6009 OEM device.

Table 4. NI USB-6008/6009 OEM Device Components

Component		Reference Designator(s) on PCB	Manufacturer	Manufacturer Part Number	Part Specifications
USB connector		J002	AMP	787780-1	—
USB cable, 2 m		—	NI	184125-02	—
34-pin connector		J004	3M	N2534-6002RB	—
34-pin mating connector		—	3M	8534-4500JL (or equivalent)	—
Mounting Standoff *	Using 34-pin board mount socket	—	NI	745798-01	3/16 in. HEX female-to-female, 14 mm long
	Using ribbon cable	—	NI	745830-01	3/16 in. HEX female-to-female, 1/4 in. long
Screw		—	—	—	M3 × 0.5, 4–40 mm
* To order, contact NI.					

USB-6008/6009 OEM Device Specifications

Most specifications of the USB-6008/6009 OEM device are listed in the *USB-6008/6009 User Guide and Specifications* document on ni.com/manuals. The following sections contain exceptions to the main specifications:

External Voltage



Note 2.5 V output is not available.

Physical Characteristics

Dimensions	8.76 cm × 5.72 cm × 1.55 cm (3.45 in. × 2.25 in. × 0.610 in.)
I/O connector	3M, 4-wall header (part number: N2534-6002RB)
Weight	1 oz

Where to Go for Support

The National Instruments Web site is your complete resource for technical support. At ni.com/support you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

National Instruments corporate headquarters is located at 11500 North Mopac Expressway, Austin, Texas, 78759-3504. National Instruments also has offices located around the world to help address your support needs. For telephone support in the United States, create your service request at ni.com/support and follow the calling instructions or dial 512 795 8248. For telephone support outside the United States, contact your local branch office:

Australia 1800 300 800, Austria 43 0 662 45 79 90 0,
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Czech Republic 420 224 235 774, Denmark 45 45 76 26 00,
Finland 385 0 9 725 725 11, France 33 0 1 48 14 24 24,
Germany 49 0 89 741 31 30, India 91 80 41190000,
Israel 972 0 3 6393737, Italy 39 02 413091, Japan 81 3 5472 2970,
Korea 82 02 3451 3400, Lebanon 961 0 1 33 28 28,
Malaysia 1800 887710, Mexico 01 800 010 0793,
Netherlands 31 0 348 433 466, New Zealand 0800 553 322,
Norway 47 0 66 90 76 60, Poland 48 22 3390150,
Portugal 351 210 311 210, Russia 7 095 783 68 51,
Singapore 1800 226 5886, Slovenia 386 3 425 4200,
South Africa 27 0 11 805 8197, Spain 34 91 640 0085,
Sweden 46 0 8 587 895 00, Switzerland 41 56 200 51 51,
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